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AFAPL-TR-65-91

COMPLETION OF FABRICATION AND ASSEMBLY OF THERMAL MANAGEMENT SYSTEM FOR DYNA-SOAR (X-20)

A. B. Chase

AiResearch Manufacturing Company
A Division of The Garrett Corporation

TECHNICAL REPORT AFAPL-TR-65-91
December 1965

Air Force Aero Propulsion Laboratory
Research and Technology Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

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Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

FOREWORD

The work described in this report was performed under Contract AF 33(615)-1898 sponsored by:

Air Force Aero Propulsion Laboratory
Research and Technology Division
Air Force Systems Command
United States Air Force

The program was under the technical direction of F. L. L'Hommedieu at the Aero Propulsion Laboratory and John G. Kimball at AiResearch.

This contract is a continuation of the work performed under Contract AF 33(657)-7132, which covered the development of a cryogenic thermal management system for the Air Force X-20 (Dyna-Soar). The work performed under the continuation contract was the fabrication and assembly of the system that had been developed prior to cancellation of the former contract.

The contractor report number for this document is DS-273. The manuscript was released by the author in April 1965 for publication as an RTD technical report.

Publication of this technical documentary report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

Glenn M. Kevern
Chief, Energy Conversion Branch
Aerospace Power Division

ABSTRACT

Several components for the X-20 (Dyna-Soar) thermal management system were in final fabrication when the original Dyna-Soar contract was cancelled. The components for three systems were refurbished and, where necessary, remanufactured and then assembled, and acceptance tested. Two sets of components were shipped to the Aero Propulsion Laboratory, and one set was delivered to the government-owned, AiResearch-operated cryogenic test facility at Boron, California, for system tests. The results of the system tests are presented in Technical Report AFAPL-TR-65-201, which is published and distributed concurrently. The thermal management system is designed to remove heat from several heat-generating sources on the X-20 space vehicle, and to return a portion of the heat to the hydrogen storage tank to maintain tank pressure. The system employs an aqueous ethylene glycol heat-transport fluid to connect the various heat sources to the heat sink. The heat sink is cryogenic hydrogen, which is stored in the supercritical state as fuel for the auxiliary power unit (APU). The distinguishing feature of this system is its ability to proportion, as required, the total hydrogen flow to the APU and the cooling load, while maintaining system stability and logic over tank pressurization, heat rejection, and APU fuel demand.

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SECTION I

INTRODUCTION

This document is the final technical report covering the work performed by AiResearch Manufacturing Company, a division of The Garrett Corporation, under Contract AF 33(615)-1898 with the Air Force Aero Propulsion Laboratory. This contract is one of two related contracts. The first, the subject contract, is for the manufacture, assembly, testing, and delivery of components of the X-20 (Dyna-Soar) cryogenic hydrogen thermal management system. The second contract is for the performance of system tests. The system test work will be accomplished under Contract AF 33(615)-2085 with the Air Force Flight Dynamics Laboratory.

AiResearch was a major subcontractor on the Dyna-Soar program, developing a sophisticated thermal management system to perform the following functions:

a. Maintain the supercritical hydrogen storage tank at constant pressure throughout the schedule of hydrogen withdrawal rates.

b. Regulate the hydrogen flow to meet the heat rejection loads of all internal equipment and of the pilot.

c. Proportion the total hydrogen flow to the auxiliary power unit (APU), and the cooling load as required, while maintaining system stability and logic over tank pressurization, heat rejection, and APU fuel demand.

The development program was terminated by contract cancellation at the time flight-configuration components were undergoing final assembly for complete system development tests.

Recognizing the advanced potential of this cryogenic hydrogen system, the Air Force Aero Propulsion Laboratory and the Air Force Flight Dynamics Laboratory initiated support for a program to take advantage of much of the technology that would otherwise be dissipated in termination. Under this program, three sets of the flight-configuration hardware have been completed. Two sets have been delivered to the Aero Propulsion Laboratory, and the third set (plus some spares) will be incorporated into a system and subjected to a comprehensive test program. The system tests will demonstrate the present capability of the system as well as permit an examination of its applicability to future programs, such as a space laboratory ferry vehicle.

Since the work accomplished under this contract consisted entirely of fabrication and assembly, there is no technical accomplishment to report. The major part of this report, therefore, is devoted to descriptions of the system components and presentations of component performance data. This information fulfills part of the information reporting requirements of the contract. The submittal of the balance of the required information is indicated in Section 2.

The work under Contract AF 33(615)-1898 was performed during the period August 1964 to April 1965.

An item-by-item summary of the completion of the work statement is presented in Section 2. The system description and performance data are presented in Section 3.

SECTION 2

CONTRACT COMPLETION

This section presents an itemized summary of the completion of the Statement of Work, Exhibit "A" of the contract. The contract items are indented.

> 1. Complete the manufacturing and assembly of hydrogen cooling equipment as defined in Boeing Source Control Drawing 10-20917. Two (2) ship-sets of packages shall be completed.

The ship-sets of packages have been completed and shipped.

> 2. Reactivate the cryogenic test facility including the data acquisition and reduction equipment. This equipment shall be used for performing the "Minimum Acceptance Testing" (per Paragraph 3 below) and shall be sufficiently flexible to perform the development testing of the completely assembled hydrogen cooling system to evaluate the total system controls design.

The data acquisition equipment, leased from Data Craft, Inc., has been reactivated and has been checked out during component acceptance tests. Data reduction services have also been contracted. The equipment and services will be used for system tests to be conducted under Contract AF33(615)-2085.

> 3. Perform acceptance testing to demonstrate that the units (packages) to be shipped are of a high quality and meet minimum Safety-of-Flight characteristics. This testing shall demonstrate structural soundness and a minimum of performance demonstration, i.e., only maximum and minimum loads need to be demonstrated. These tests will include as a minimum requirement the proof pressure tests, operational tests, room temperature leak tests, and other acceptance tests as proposed and described in the Appendix (Section 6, Section 7, Section 8, Section 9, and Acceptance Test Plan for X-20 (Dyna-Soar) - 8 package) of The Garrett Corporation Proposal (Report No. DS-254-R) dated 27 January 1964,' incorporated herein by reference. Approval of the Air Force project engineer will be obtained prior to each major acceptance test with sufficient time allotted for him to witness any such test at his discretion.

The acceptance tests were performed as required. Copies of the acceptance data sheets were transmitted with the packages. The tests were conducted under surveillance of the resident Air Force Quality Control Representative. Evidence of Air Force witnessing is included on the data sheets.

4. Spare parts shall be included as individual items, assembled components, or subassemblies. The degree of assembly, to be mutually agreed upon by the contractor and the Air Force, shall be held to that level most practical for replacement. The number of spares should be from two to four replacements within the limits of the number of components being fabricated at the initiation of work. These spares will be checked out to demonstrate individual functional capability. The quality of components shall be at least as good as research quality. Formal quality control is not required beyond that generally exercised in other R&D programs.

Spare parts have been assembled and are being held as spares for the system test. At the conclusion of the system test, spare assemblies as available will be delivered as requested.

5. The following information shall be reported:

a. Certification of the successful accomplishment of Acceptance Testing shall accompany each ship-set of hardware.

Data sheets showing evidence of appropriate witnessing were transmitted with each package.

b. Predicted performance data for each package of the system shall be included. This information shall be essentially a performance map for each of the units. This information must be reported only once and not with each ship-set of hardware.

Performance estimates, including test data on principal components, are presented for each package in the System Description, Section 3.

c. Informal assembly instructions and informal operating instructions shall be furnished as requested.

This information is also presented in Section 3.

d. Drawings shall be furnished for all hardware items. These drawings shall generally be of the quality existing at the time of initiation of work or copies of engineering drawings which the contractor has for his own internal use commensurate with the R&D nature of this work.

A complete set of drawings will be furnished as a separately delivered item.

e. A complete parts listing with the original vendor serial numbers or part numbers, as well as the Boeing serial numbers or part numbers, shall be included for eash ship-set package.

The parts lists will be furnished separately with the drawings.

f. A thorough discussion of technical problem areas and possible engineering solutions on each system component and its system interactions shall be included in the final report. This discussion will define both the system component and total system state of the art at the time of contract completion and delineate technical areas requiring additional investigation to provide a flightworthy vehicle cryogenic thermal management system.

There are no remaining technical problem areas within the scope of this contract, which covers fabrication and assembly of the system components. Engineering design and development of the components had been completed under the original Dyna-Soar contract, and any fabrication and assembly problems encountered in the course of the current contract have been solved.

System interaction will be explored during the system tests under Contract AF33(615)-2085, and appropriate discussion will be included in the final report for that contract.

6. All special tooling previously developed under Air Force funding by the contractor for this system shall be delivered to the Air Force when requested.

Tooling not otherwise disposed of previously by the Air Force is available for delivery on request.

7. The contractor will provide a minimum of two-hundred hours of engineering and technician support at the AF Aero Propulsion facility, as required, to assist in the setup, testing, and checkout of equipment delivered under this contract.

Engineering and technician support is available on request.

8. The contractor shall permit Air Force engineers and technicians from the procuring agency to visit his facility to acquire first-hand knowledge of the manufacture, assembly, and test of this hardware (particularly the more complex items) to allow more satisfactory use after delivery to the Air Force.

Air Force engineers and technicians are invited to visit AiResearch at any time. Although there were no visitors during performance of the subject contract, visitors were received during the subsequent system test conducted under Contract AF33(615)-2085. The results of the system test are presented in Technical Report AFFDL-TR-65-201, December 1965.

9. Upon completion of this contract, the contractor shall provide to the contracting officer a complete listing of all Air Force equipment and parts purchased for, or required by this contract with a statement of condition of each item.

Complete lists of special tools or equipment purchased under this contract will be transmitted under separate cover.

SECTION 3

SYSTEM DESCRIPTION

THE SYSTEM AS A WHOLE

The thermal management system is designed to remove heat from a number of separate heat-generating sources on the X-20 (Dyna-Soar) space vehicle. The system employs an aqueous ethylene glycol heat-transport fluid to connect the distributed heat sources to the heat sink. The heat sink is cryogenic hydrogen, which is stored in the supercritical state as fuel for the auxiliary power unit (APU).

The heat sources cooled by the system include the pilot compartment (man and electronics), the equipment compartment, the hydraulic system, electronic cold plates, and the APU alternators.

An additional function of the system is to return a portion of the heat load to the hydrogen storage tank to maintain the hydrogen in the supercritical state under varying withdrawal rates determined by APU fuel and cooling demands.

The system is shown schematically in Figure 1. As shown in the schematic, the glycol solution circulates through two independent closed circuits, or loops. The two loops are virtually identical, with the exception that one loop serves the pilot compartment and the other serves the equipment compartment.

The system was designed to be furnished in the form of five separate components, or packages, to be integrated into the X-20 vehicle by the vehicle contractor. The five packages designed and built by AiResearch are:

Package Name	AiResearch Part Number	Short Name
Pilot Compartment Cooling Unit	178380	-1 Cooling Unit
Equipment Compartment Cooling Unit	178390	-3 Cooling Unit
Hydraulic Fluid Cooling Unit (two units per shipset)	154910	-4 Cooler
Glycol Dual Pump Unit	178410	-7 Pump
Glycol Temperature and Hydrogen Pressure Control	179140	-8 Package

The cold plates and the alternator cooling circuits were intended to be contractor-furnished.

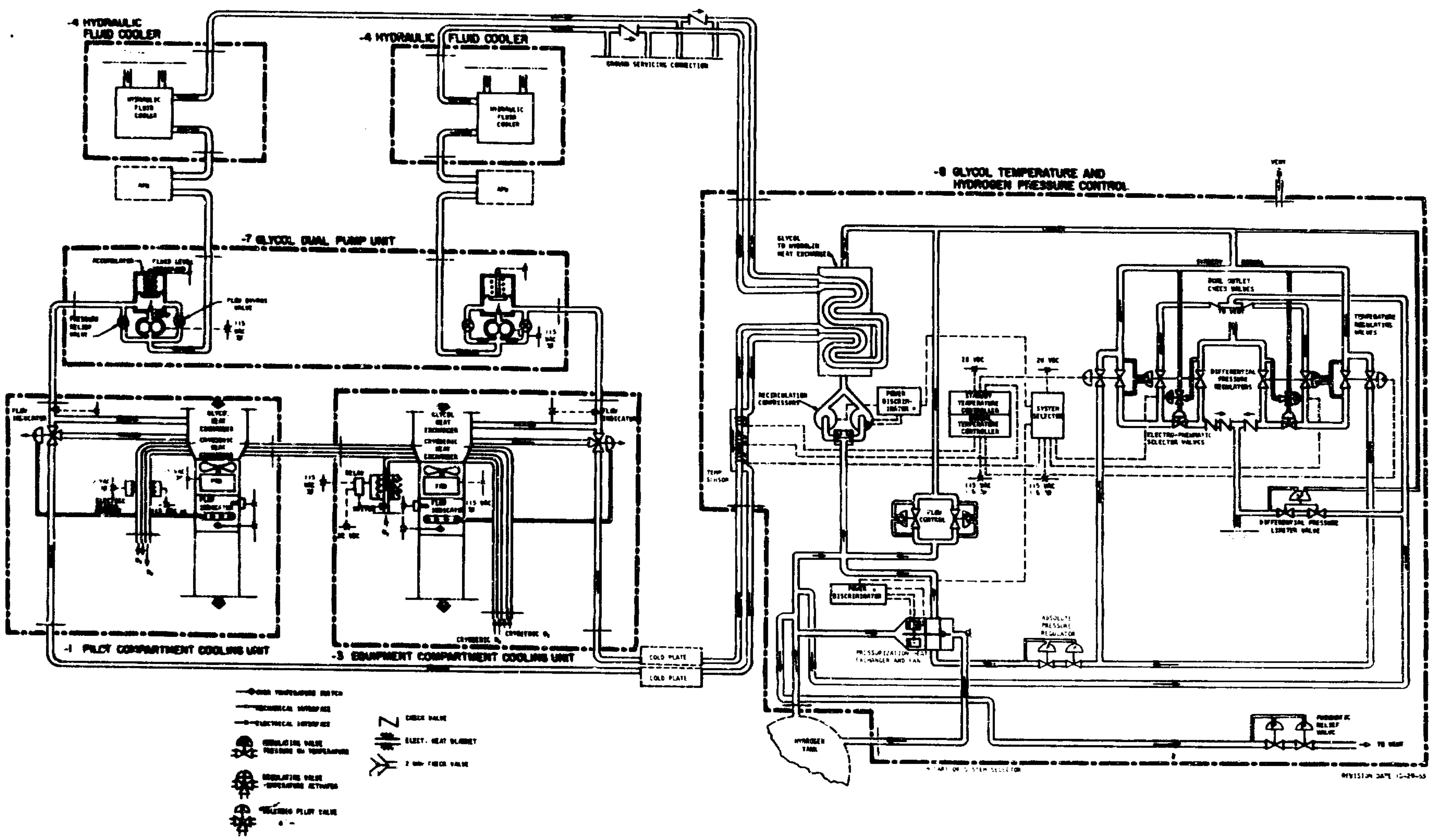

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Figure I. Thermal Management System Schematic

The short names, which are derived from the original contractor's dash numbers, have evolved as the conversational terms for these units and are used frequently in this report for brevity.

Each package is individually described in detail later in this section. Briefly, the -1 and -3 compartment cooling units are fan-equipped air-to-glycol heat exchangers. The -4 hydraulic cooler is a hydraulic fluid-to-glycol heat exchanger. The -7 pump contains separate gear-type pumps and accumulators for each of the two glycol loops. The -8 package provides the glycol-to-hydrogen heat exchanger and the electronic and pneumatic controls and valves required to accommodate the often unmatched demands of the APU and the cooling system. The -8 package also manages the heat return to the hydrogen storage tank for tank pressure control.

The boundary of each package is indicated by the heavy dashed lines in the system schematic. Each penetration of a boundary by a fluid circuit represents an interface with the contractor-installed plumbing or equipment. Additional electrical and cryogenic connections which do not appear in the schematic are defined in the individual component descriptions that follow.

THE -1 PILOT COOLING UNIT, PILOT COMPARTMENT COOLING UNIT 178380-1-1

Description

1. Cooling Unit Function

The pilot compartment cooling unit is designed to cool and circulate the atmosphere in the Dyna-Soar pilot compartment. It consists mainly of a heat exchanger, a fan, and a thermostatic control. The fan draws the compartment atmosphere (a mixture of 44 percent O_2 and 56 percent N_2 by weight, and referred to in this report as "air") through the heat exchanger where the air is cooled by chilled glycol (a eutectic solution of ethylene glycol and water plus corrosion inhibitors, defined in the paragraph on assembly and operation below). The air discharge temperature is regulated to 45°F by the thermostatic valve, which controls the proportion of total available glycol flow that passes through the heat exchanger.

The cooling unit also warms the makeup oxygen and nitrogen that are fed to the compartment from cryogenic storage vessels. The makeup gases are warmed by heat exchange with the compartment airstream in the cooling unit and, when required, by a pilot-controlled electric heater.

2. Physical Features

Photographs of the cooling unit assembled and partially disassembled, are shown in Figures 2 and 3. This unit was a test unit, and all details were not of the final configuration; the photographs, however, show the general appearance and arrangement of major components. The unit in Figure 3 is complete except for some tubing and parts of the wiring harness. The working details are illustrated in the cutaway schematic, Figure 4.

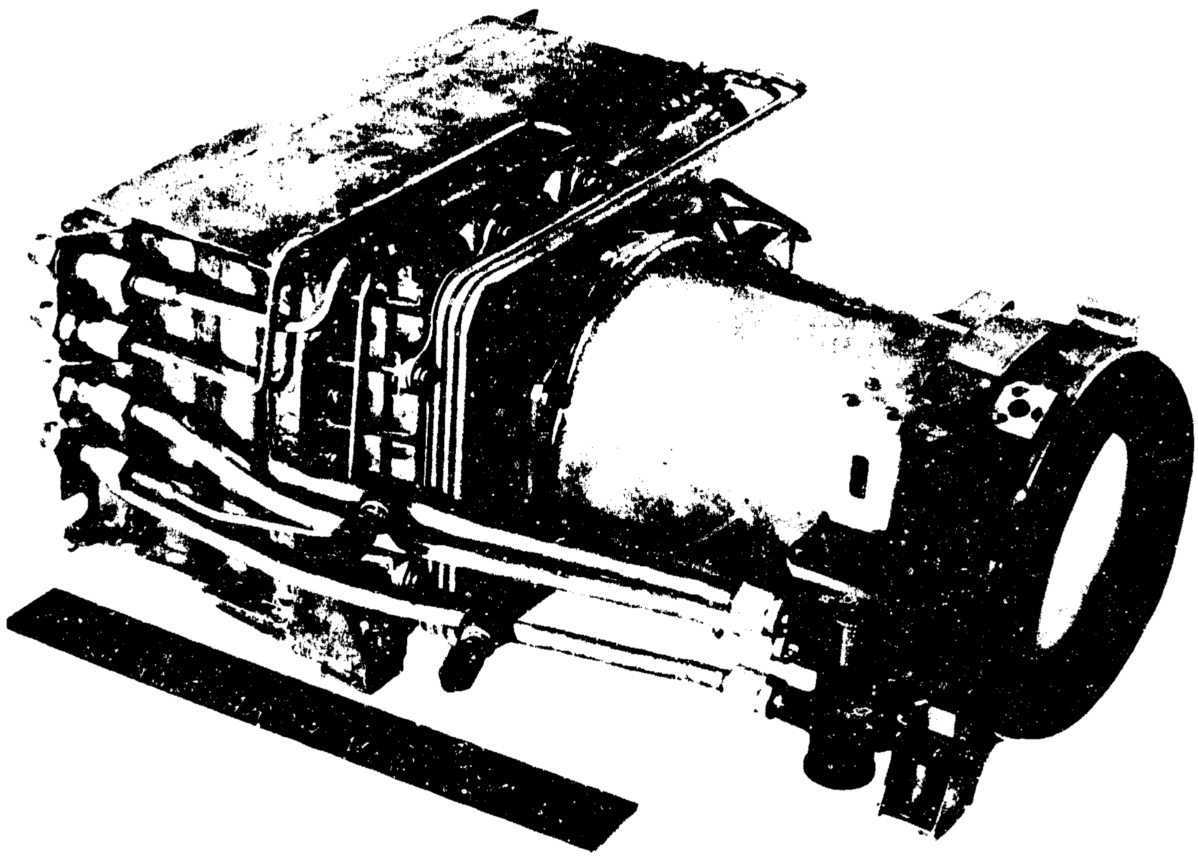

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Figure 2. Pilot Compartment Cooling Unit

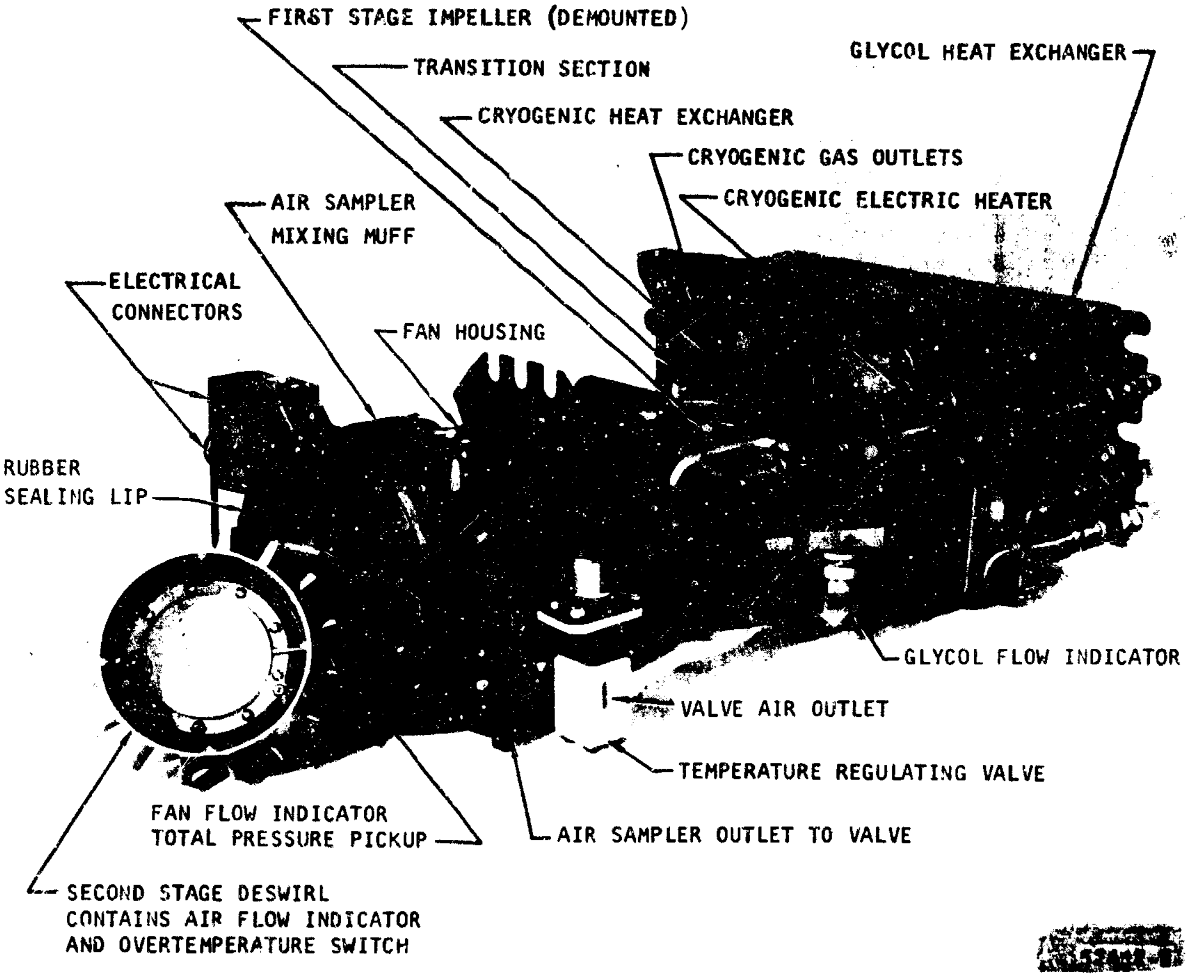

Figure 3. Pilot Compartment Cooling Unit Partially Disassembled

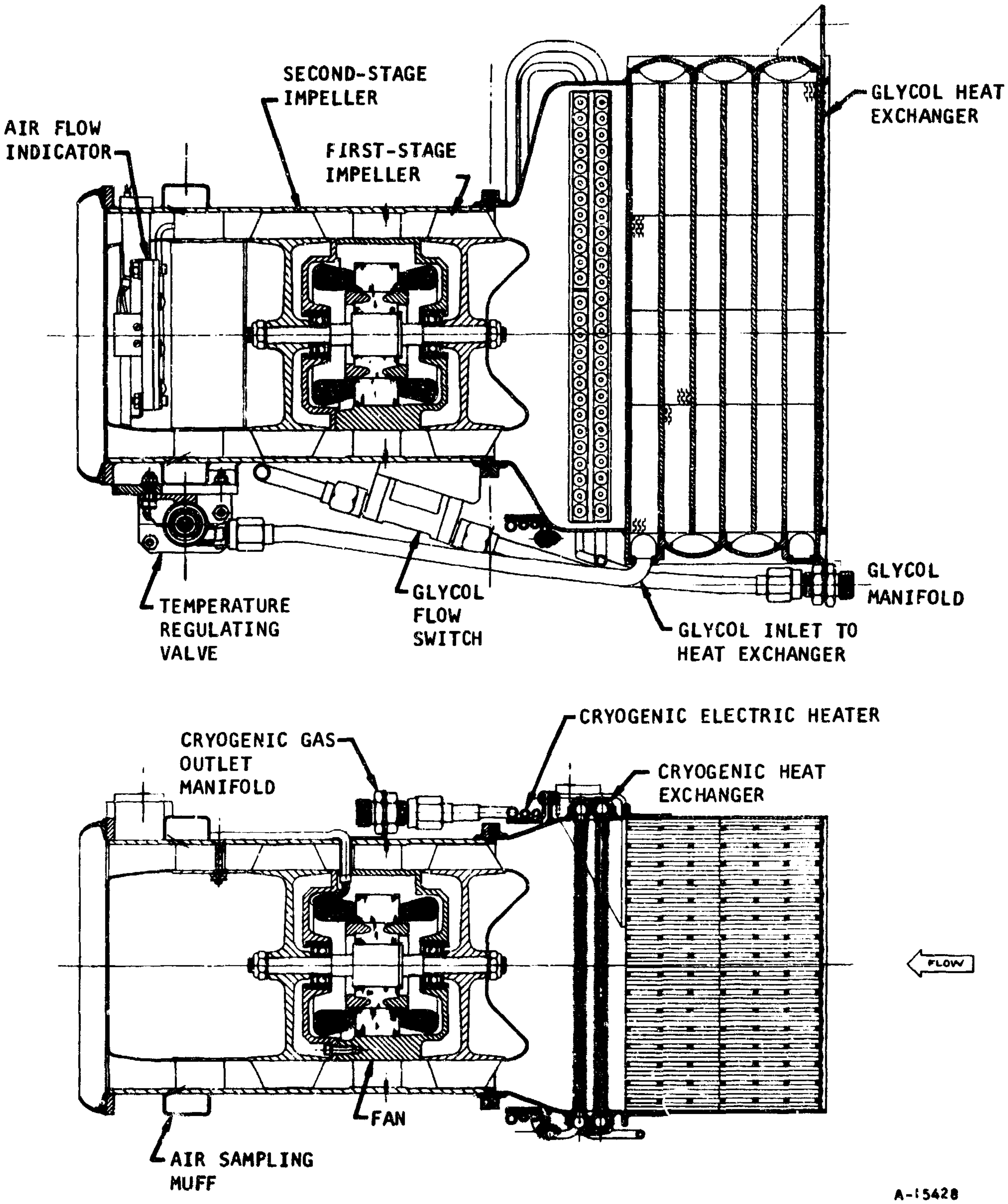

Figure 4. Cutaway Schematic of Pilot Compartment Cooling Unit

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In addition to the heat exchanger, fan, and temperature regulating bypass valve already mentioned, three warning or indicator circuit devices are included in the following individual component descriptions. These devices are the airflow indicator, air overtemperature indicator, and the glycol flow indicator. These devices all contain switches that activate the vehicle warning circuits, which are presumed to consist of indicator light bulbs.

3. Heat Exchanger Assembly

The heat exchanger assembly comprises the glycol-to-air heat exchanger, the cryogenic (makeup gas) heat exchanger, the cryogenic electric heater, the transition section (to mate with the fan), related plumbing connections, and two of the four unit mounting points.

a. Glycol Heat Exchanger--The glycol-to-air, or simply the glycol, heat exchanger is of all-aluminum, brazed-and-welded, plate-fin construction. It has six glycol passes and a single, straight-through air pass in a cross-counterflow arrangement. The glycol tubes are single-sandwich, 0.1 in. high, while the air passages are triple-sandwich construction using three layers of 0.1-in.-high fins for a total height of 0.3 in. The tubes next to the side plates are reduced to a double sandwich. There are 16 glycol tubes per pass, and 17 air tubes per pass including those adjoining the side plates.

b. Cryogenic Heat Exchanger--The cryogenic heat exchanger is located in the transition section between the glycol heat exchanger and the fan. It consists of two banks of finned tubes extending across the airstream between tubular turning pans. It is made entirely of aluminum and is joined entirely by welding. The fins are integral with the tubes, being formed by machining larger-OD tubes.

The heat exchanger has a separate circuit for each of the three makeup circuits, nitrogen, normal oxygen, and emergency oxygen. One bank warms the nitrogen, while the other bank is divided between the two oxygen circuits. The nitrogen bank contains 26 tubes, 8 passes, arranged in six 3-tube passes and two 4-tube passes. The normal oxygen circuit has 14 tubes, each tube a separate pass, and the emergency oxygen circuit has 12 tubes, each tube a separate pass. All tubes are 1.0 in. ID, with a minimum wall thickness after machining of 0.015 in.

c. Electric Heater--An electric heater is included as an adjunct to the cryogenic heat exchanger, which, with a customer-furnished Variac control, would enable the pilot to control makeup discharge temperature from 40°F to 90°F. The heater is in the form of a silicone rubber heating strip cemented along one side of a metal backing plate, which nests the tubes of the three makeup circuits side-by-side for a running length of about 15 in. downstream of the cryogenic heat exchanger. The blanket contains two separate resistance wire circuits laminated in silicone rubber.

4. Fan

The fan is a two-stage, axial-flow, fixed-geometry, ducted fan directly driven by a three-phase, 400 cps, 115/200 v a-c, moderate-slip, induction motor. The two impellers are mounted at opposite ends of the motor. The motor and impellers are centerline-mounted in a cylindrical duct, or housing. Fixed geometry deswirl vanes are provided in the housing for each stage. The first-stage deswirl vanes form the motor mounting structure.

The inlet end of the fan housing has a bolt flange for attachment to the transition section of the heat exchanger assembly. The discharge end of the fan housing has a rubber sealing lip for mounting the unit against a bulkhead opening.

The housing contains air sampling passages to divert a small portion of fan discharge air through the thermostatic valve. To ensure that this sample is representative of average discharge temperature, eight bleed slots are spaced 45 degrees apart circumferentially in the housing downstream of the second-stage deswirl vanes. The slots lead into a common mixing muff, or plenum, which, in turn, opens directly into the thermostat cavity of the temperature-regulating valve. From the valve, the air sample exhausts to the ambient (pilot compartment) atmosphere. The sampling air flow does not exceed 2 percent of the total flow.

In addition to containing the fan itself, the fan housing contains the temperature regulating valve, the air flow indicator, the overtemperature indicator, the cryogenic outlet connections, and the electrical connectors. The valve and the connectors are external, while the warning indicators are buried inside the discharge fairing. The housing also provides two of the four cooling-unit mounting points, which accounts for its relatively heavy structure.

All structural parts of the fan and housing are made of aluminum.

5. Temperature Regulating Valve

Figures 5 and 6 show a photograph of the temperature regulating valve disassembled and a cross-sectional drawing of the internal mechanism assembled.

The valve regulates discharge air temperature by dividing the available chilled glycol between the heat exchanger (core) and a bypass line. The flow divider is a dual-poppet assembly, which is stroked axially between two seats in a cylindrical housing. One poppet controls the core flow, while the other controls the bypass flow. The glycol inlet is between the poppets. Each circuit can be modulated throughout the flow range from shutoff to fully open. The poppet relationship is such that one circuit is fully open when the other is shut off and vice versa. Valve operation is identical in the -1 and -3 cooling units; the -3 valve, however, has an additional port. This fourth port receives the core return flow so that the core outlet and bypass flows join inside the valve housing rather than at a tee downstream of the valve.

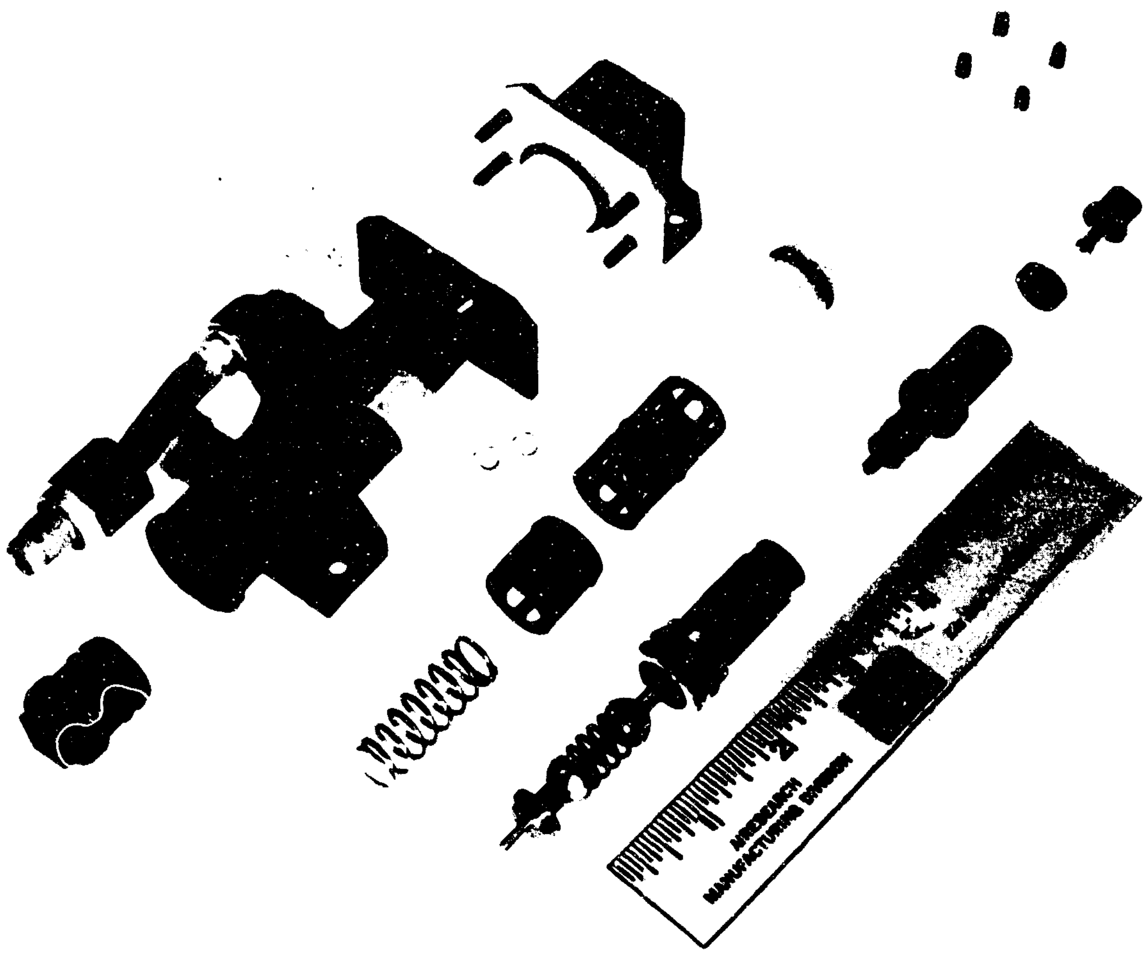

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Figure 5. Temperature Regulating Valve, Disassembled

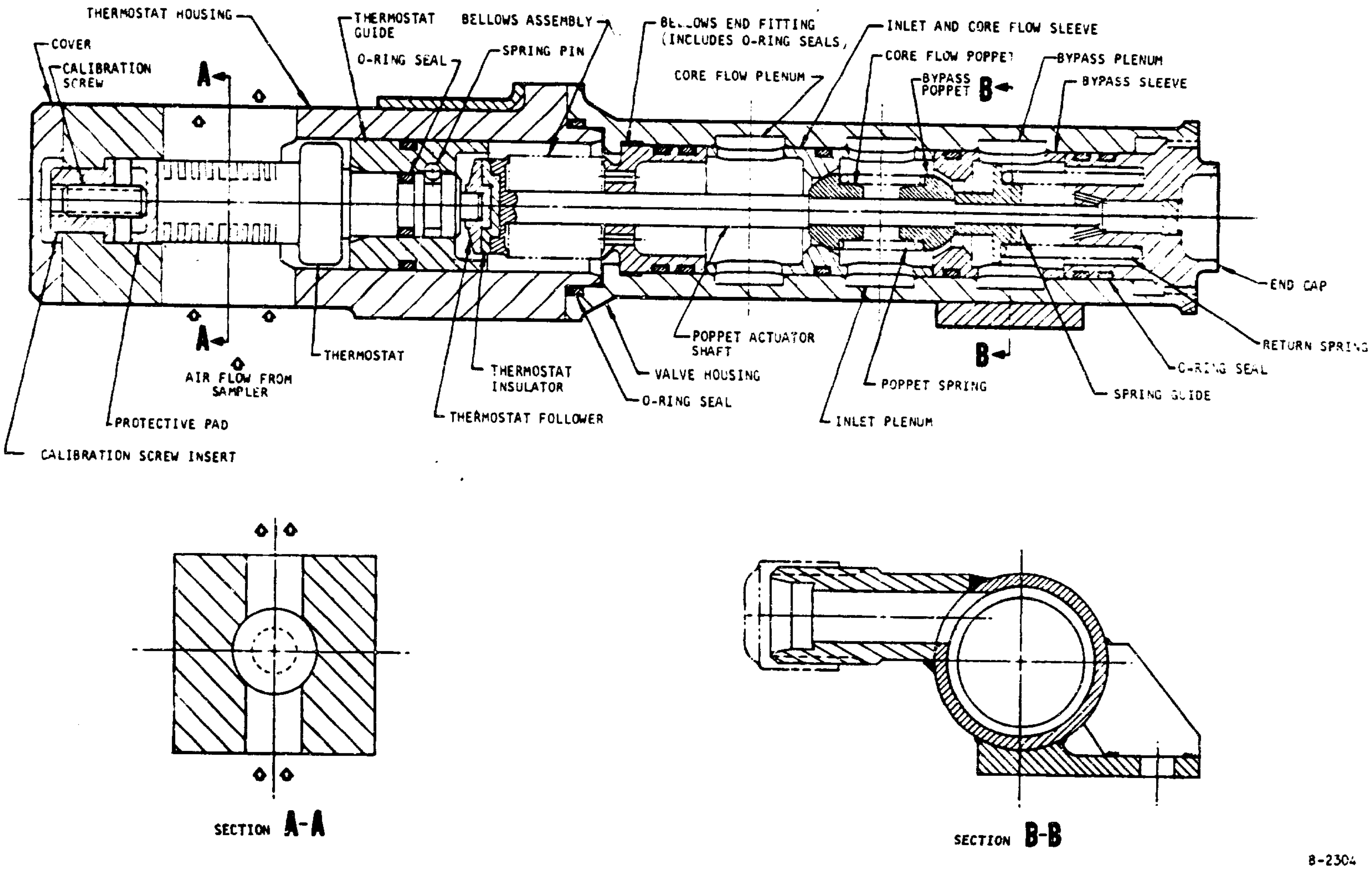


Figure 6. Temperature Regulating Valve, Working Details

The poppet is stroked by a thermal linear actuator, or thermostatic power element. The element utilizes the expansion and contraction incident to the phase change of a wax mixture. The thermostat is a Vernatherm power element, manufactured by American Standard Controls Division. Increasing the air temperature extends the thermostat plunger to reduce bypass flow and increase core flow. Decreasing the air temperature reverses the action. The position of the thermostat relative to the poppet assembly is adjustable by means of a calibration screw.

The thermostat housing, or air section of the valve, is maue of Delrin 500* to minimize the heat leak from the thermostat to the cold glycol in the poppet section of the valve. This is necessary because of the relatively low air flow across the thermostat. To further minimize the influence of the glycol temperature, and to obtain the highest response to air temperature changes, the air temperature sensing surface was made as large as practical by the addition of fins to the thermostat case. Like the finned tubes in the cryogenic heat exchanger, the fins were formed by machining an oversized thermostat case.

Except for the thermostat section, the valve housing seats are aluminum. The poppet is aluminum and the stem (actuating rod) is 17-4PH stainless steel. The return and overtravel springs are steel. The exterior of the Vernatherm element is a copper alloy. An AM350 steel bellows is used to seal the air section from the glycol section and to allow movement of the actuator rod.

6. Air Flow Indicator

This unit consists mainly of a diaphragm and a normally closed, single-pole, single-throw, Micro Switch manufactured by Honeywell, mounted in a shallow cylindrical housing. Pressure sensing lines apply the fan discharge total pressure and ambient (pilot compartment) static pressure to opposite sides of the diaphragm. When the fan is running, the fan pressure rise causes the diaphragm to open the switch and to hold it open at fan flows above a preset flow, about 70 percent of full fan flow. The diaphragm is preloaded by an adjustable spring which provides a method of calibration. The unit is mounted inside the fairing in the deswirl section. In Figure 3, the deswirl has been demounted and turned to show the air flow indicator housing. The unit is made mostly of aluminum; the diaphragm, spring, switch, etc. are made of other appropriate materials.

7. Air Overtemperature Indicator

This unit is a commercially available Klixon thermal switch, manufactured by Texas Instruments, Incorporated. The switch is a single-pole, single-throw design with a snap-action, bimetallic disk actuator. It is calibrated by the manufacturer to close in the temperature range of 60°F to 65°F when the temperature is increasing and to reopen at a temperature above 55°F when the temperature is decreasing. The switch is mounted inside of, and in intimate contact with, a thin-wall portion of the discharge fairing. It is not shown in the photographs or in the cross-sectional sketch.

*E. I. du Pont de Nemours and Co., Inc.

8. Glycol Flow Indicator

The glycol flow indicator is a flow-actuated switch located in the glycol line at a point downstream of the union of the core and bypass flows so that total glycol flow is sensed. The switch is held open at glycol flows above 2.5 lb per min and closes before the glycol flow drops below 1 lb per min.

The unit consists of a venturi, a differential bellows, an actuator rod, and a normally closed, single-pole, single-throw, microswitch. The venturi inlet-to-throat differential is applied across the bellows, which actuates the switch through a push rod. The push rod and switch are isolated from the glycol by sealing bellows. The switch is mounted in a threaded cap by epoxy potting. The switch point is set by adjustment of the threaded cap.

Assembly and Operation

The cooling unit is designed for operation in a compartment atmosphere ranging from sea level atmosphere to pure oxygen. The design atmosphere for flight conditions consists of 56 percent nitrogen and 44 percent oxygen by weight at 7.35 psia. The nitrogen and oxygen were to conform to Specifications MIL-P-27401A and MIL-O-27210, respectively. Air or 100 percent nitrogen may be used satisfactorily for all test purposes except where oxygen compatibility is to be observed.

It may be necessary to use relatively dry compartment atmosphere to prevent frost accumulation on the cryogenic heat exchanger. If the fluid temperatures (which depend on the choice of test fluid) inside the cryogenic heat exchanger are such that the tube walls will be below freezing, it is recommended that the compartment atmosphere dew point not exceed 20°F. The frosting phenomenon is discussed more fully in the section covering the -3 cooling unit, which is more susceptible to freezing because of the cryogenic temperatures in the heat exchanger.

The cryogenic makeup circuits are designed for operation with pure gases conforming to the applicable military specifications. However, heat transfer properties are sufficiently similar so that nitrogen may be used in the oxygen passages for safety during tests. For system tests in which it is necessary to simulate only the cryogenic cooling effect, any convenient fluid may be used, with flow rates or temperatures, or both, adjusted accordingly.

The glycol fluid to be used should be an aqueous ethylene glycol solution with inhibitors prepared as follows:

	Parts by Weight	Pounds for 100 gals
Ethylene glycol (per MIL-E-9500)	65.00	571.24
Distilled water	34.83	306.20
Triethanolamine phosphate	1.75	15.40
Sodium mercaptobenzothiazole (50 percent aqueous solution by weight)	0.34	2.99
	101.92	895.83

The triethanolamine phosphate will consist of the following proportions:

	Parts by Weight
Triethanolamine	13.1
Phosphoric acid (85 percent aqueous solution by weight)	2.3

The specific gravity, as measured by hydrometer at solution temperature of 75°F, shall range between 1.083 and 1.087.

The pH value of the solution shall range from 7.1 to 7.7 and may be adjusted using either sodium hydroxide solution or phosphoric acid as required.

The ethylene glycol mixture shall be allowed to stand 24 hr after preparation and then filtered through a filter with 35-micron absolute rating.

Except in the deliberate attempt to optimize the heat transport fluid, it is recommended that the test fluid conform closely to that given above.

The fluid ports are defined by Envelope Drawing SK 44512, submitted separately. The fluid fittings are standard MS flareless bulkhead fittings instead of the special double-seal Mil Flo fittings specified by the original contractor. At the time that parts were procured, the appropriate Mil Flo fittings were not available, so standard fittings were used in the interior. MS-to-Mil Flo adapters are now available from the Mil Flo Corporation, Dayton, Ohio.

The fan requires 115/200-v, three-phase, four-wire, 400-cps electric power, and the electric heater requires two separate sources of 115-v, single-phase, 400-cps power. The electrical connectors are defined in Drawing SK 44512. The circuit schematic for the a-c connector printed on a metallic decal applied directly to the unit.

The indicator switches are designed to operate with 28 v dc and with an external load not to exceed 5 amp for each switch. For test purposes, any convenient voltage can be used, provided the current does not exceed the rated load. AiResearch frequently uses a 6-v battery with incandescent lamps for test pruposes. The d-c connector schematic is shown on the wiring diagram label furnished on the unit itself.

The cooling units are shipped with the glycol passages drained, flushed with solvent, and dried with clean air or nitrogen. Therefore, special attention should be given, during filling of the glycol loops, to removal of trapped air.

The cryogenic passages are purged with dry nitrogen before shipment and require no special precautions in their operation.

The following switch points are listed as an aid in monitoring the warning circuits.

Fan flow indicator:

No flow increasing to 85 percent flow -- indicator on

85 to 95 percent flow -- switch point, increasing flow

Above switch point -- indicator off

72 to 65 percent flow -- switch point, decreasing flow

Below 65 percent flow -- indicator on

Air overtemperature switch:

Increasing temperature to 60°F -- indicator off

60°F to 65°F -- switch point, increasing temperature

Above switch point -- indicator on

65°F to 55°F -- switch point, decreasing temperature

Below switch point -- indicator off

Glycol flow indicator:

No flow to 2 lb per min -- indicator on

2 to 2.5 lb per min -- switch point, increasing flow

Above switch point -- indicator off

2.5 to 1.5 lb per min -- switch point, decreasing flow

Below switch point -- indicator off

Performance

The performance of the -1 cooling unit is summarized in the following listed design requirements.

Applied Conditions

Maximum heat load	354 Btu per min
Minimum heat load	60 Btu per min
Maximum rate of inlet air temperature change	
Increasing temp	15°F per min
Decreasing temp	5°F per min
Glycol flow range	
Normal	5.0 to 5.8 lb per min
Failed conditions	4.0 to 5.8 lb per min
Design point	5.43 lb per min
Glycol inlet temperature	5°F to 24°F
Cryogenic fluid flow	
Oxygen	
Normal	0.1 ±0.01 lb per min
Alternate	0.1 ±0.01 lb per min
Emergency	0.2 ±0.02 lb per min
Nitrogen	0.13 ±0.1 lb per min
Cryogenic fluid inlet temperature	
Oxygen, -3 operating	-15°F to +40°F
-3 failed	-257°F and 46 percent quality to -220°F and 31 percent quality
Nitrogen, -3 operating	-15°F to 40°F
-3 failed	-305°F to -258°F, saturated liquid

Performance

Air flow (altitude)	16.2 lb per min, minimum
Corresponding sea level Flow	29.2 lb per min
Static air pressure rise	
At 7.35 psia	4.5 in. H_2O, minimum
At 17.7 psia	2.25 in. H_2O, minimum

Air outlet temperature	$45 \pm 5^{\circ}$F
Cryogenic gas outlet temperature	
Electric heater off	40°F, minimum
Electric heater on	40°F to 90°F
Fan power consumption, maximum	650 w (altitude) 1180 w (sea level)
Cryogenic heater power consumption	140 ± 10 w (70 w each heater)

The fluid passages have been designed to withstand the following pressures.

Passage	Maximum Operating, psig	Proof psig	Burst psig
Glycol	110	165	275
Oxygen			
flow conditions	300	450	750
no flow	1506	2260	3760
Nitrogen	230	345	575

The high oxygen proof pressure required for the no-flow condition is to accommodate a peculiarity of the Dyna-Soar system in which cold, partially liquid oxygen could become trapped downstream of the pressure regulator. The oxygen passages were designed for a proof pressure of 3390 psig, a strength level obtained in part by heat treating the cryogenic heat exchanger to the T6 condition. For the units delivered under the present contract, it was decided to omit the heat treat so as not to risk tube cracking during quench because no replacements were available for the special finned tubes. It was felt that the 2260 psig proof pressure now offered was sufficiently in excess of current needs.

Other significant features of the cooling unit are:

Weight

dry	24.85	lb	(calculated)
wet	27.25	lb	(calculated)

Life: 2000 hr, with fan servicing at 500-hr intervals

The set points of the warning switches are presented in the paragraphs on Assembly and Operation above.

Detailed performance of the glycol heat exchanger, fan motor, fan, cryogenic electric heater, and temperature regulating valve are presented in the following test descriptions.

1. Glycol Heat Exchanger Performance Test

a. Procedure--The heat rejection test was run at the following conditions (total of 16 points):

	N_2-O_2 side	Glycol Side
Test Fluid	Air	Glycol-water 65-35 inhibited (RS 84)
Inlet Temp	137.6 ±1°F	18.3 ±1°F
Inlet Press	14.7 ±1 psia	40 ±2 psig
Flow	8, 16.2, 24, 32 (±2 lb per min)	2, 4, 5.43, 7 (±0.01 lb per min)

Isothermal pressure drops were conducted as a separate test and were run at a constant air temperature of 80 ±4°F and a constant glycol temperature of 18.0 ±0.5°F.

b. Results--The test results are presented in the form of curves. Figure 7 shows the thermal conductance test results. Superimposed on this curve is the calculated design UA at 5.43 lb per min glycol flow and 16.2 lb per min air flow. The test results indicate that the heat exchanger core meets the design UA. Although these results were obtained using air in the O_2-N_2 passages, the heat transfer properties of air are sufficiently close to O_2-N_2 to validate the test results. Heat balances of less than 5 percent were obtained at test points presented.

Figures 8 and 9 present the pressure drop on the heat exchanger glycol and O_2-N_2 sides. The O_2-N_2 side pressure drop was approximately 22 percent lower than the design point at design flow and 80°F air temperature. The glycol pressure drop curve shows that, at design glycol flow and 18°F, the pressure drop was 17.8 in. Hg. The substitution of air for O_2-N_2 in the pressure drop test simplified testing and is considered valid since the physical properties of these gases are similar.

2. Cryogenic Electric Heater Performance

a. Procedure--For the first part of this test, the heating elements were connected so that each element could be turned on separately. The nitrogen flow was started and adjusted to approximately 0.1 lb per min in each of the three passages. One of the two heater blanket elements was

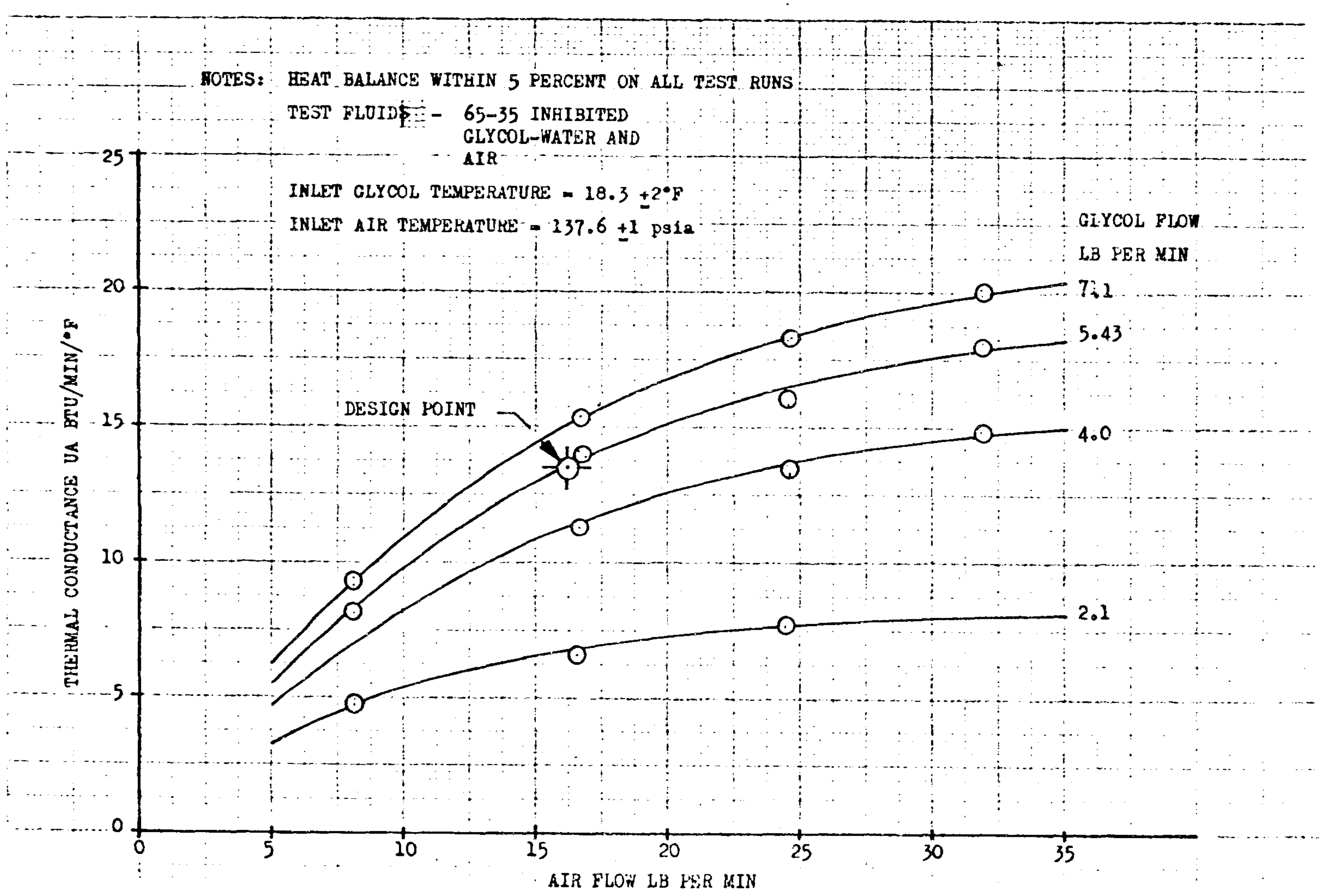


Figure 7. Pilot Glycol Heat Exchanger Heat Transfer Performance

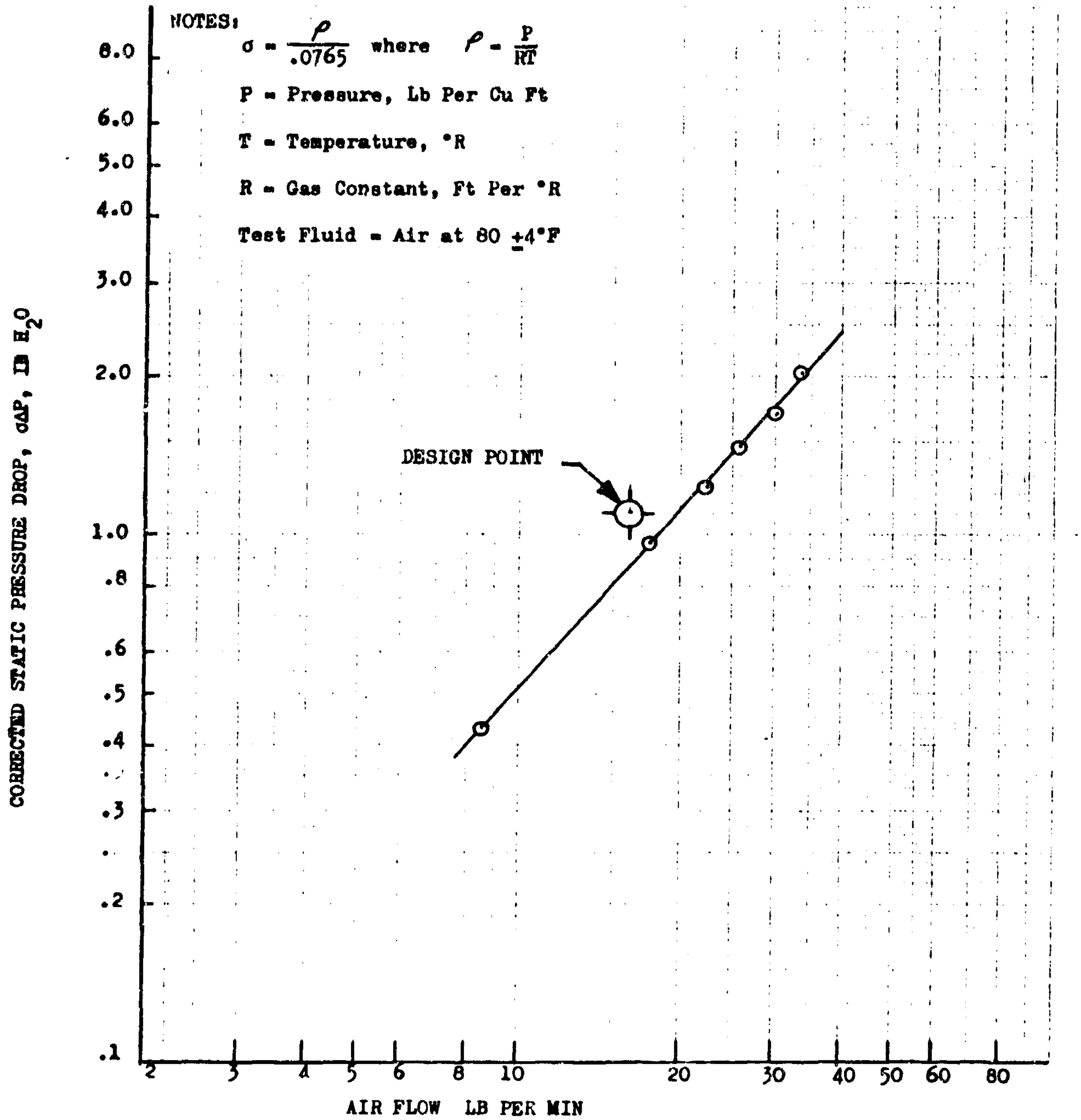


Figure 8. Pilot Glycol Heat Exchanger Air Pressure Drop

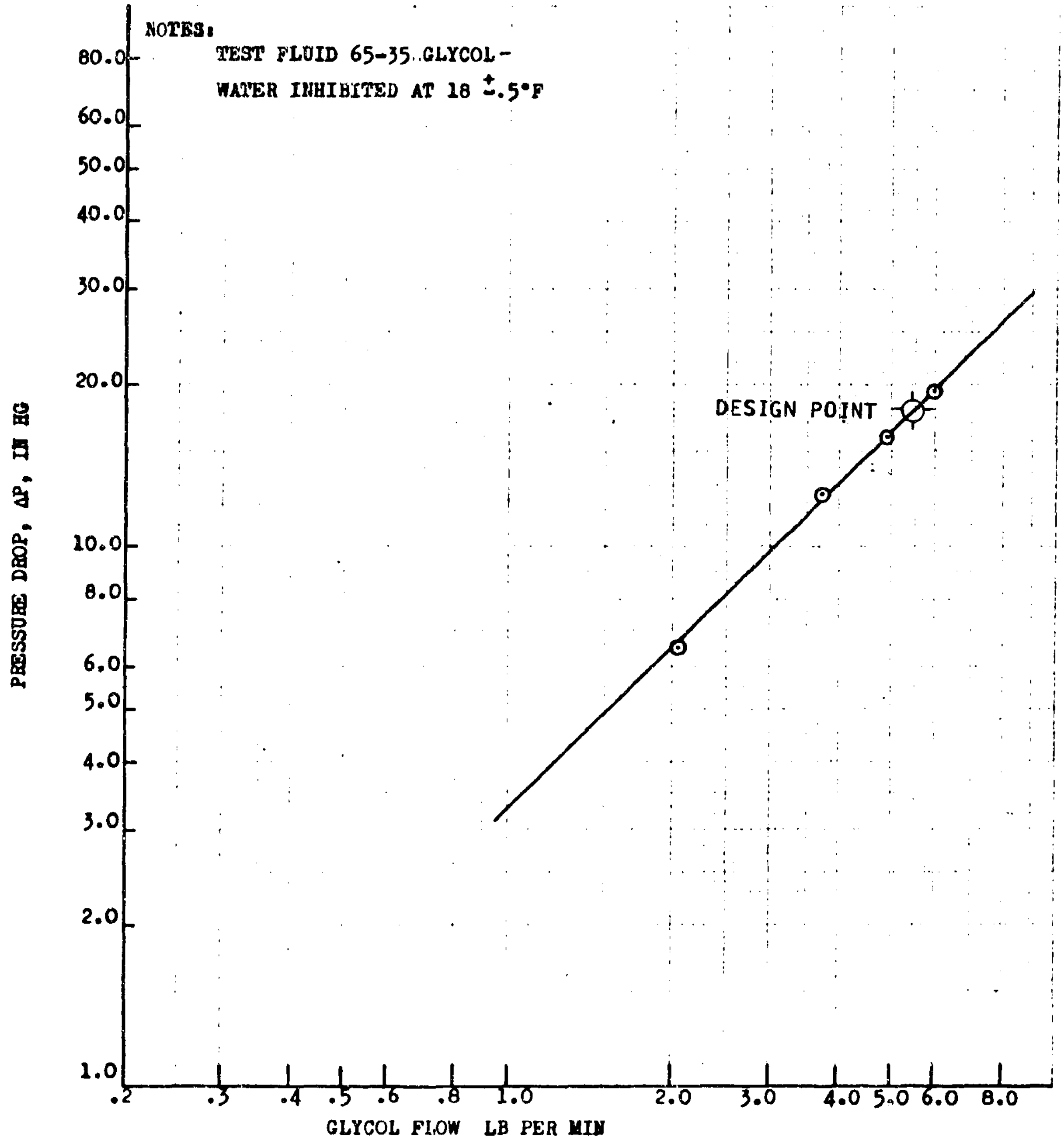


Figure 9. Pilot Glycol Heat Exchanger Glycol Pressure Drop

turned on and the inlet gas temperature was adjusted successively to approximately 20°F, 30°F, and 40°F. At each inlet temperature the outlet temperature for each of the three coils and the power consumption of the heater element were measured and recorded. This procedure was then repeated for the other heater element.

With both elements turned on and a gas flow of 0.1 lb per min in each passage, the inlet gas temperature was adjusted to approximately 10°F. The power (total for both circuits) was adjusted successively to approximately 40, 55, and 72 w (full power). For each power setting, the inlet and outlet temperatures were recorded.

b. Results--The results of the heater performance tests are shown in Table I. With full power applied, the temperature increase in the oxygen passages was 81°F to 89°F, and the temperature increase in the nitrogen passages was 75°F.

3. Temperature Regulating Valve Thermal Response Test

a. Procedure--The valve was calibrated to cause full poppet travel within a temperature range from 40°F to 50°F. The valve was cycled by varying the air inlet temperature from 40°F to 50°F to 40°F for 1 hr. Glycol flow was maintained at approximately 5.4 lb per min, 18°F, and 50 psig at the valve inlet port.

The above test was repeated by varying the inlet air temperature between 30°F, 60°F, and 30°F for 1 hr.

b. Results--The results of the thermal response test (Vernatherm element installed) are shown in Figure 10. This curve shows the glycol flow through the "HX" port as a function of the sensed air temperature for both increasing and decreasing air temperatures. Two types of runs are shown: (1) a typical run, and (2) a transient run. For the typical run, the air temperature was stabilized at each data point. For the transient run, the temperature was changed from 50°F to 40°F in approximately 20 sec, and from 40°F to 50°F in approximately 40 sec.

c. Discussion--Since the "HX" passage of the valve does not fully close until the sensed temperature has dropped to 38.5°F, the performance needs to be examined as to whether it will regulate the closing unit discharge temperature to 45 ±5°F.

When operating in the X-20 vehicle, the minimum heat load was to be 60 Btu per min. The glycol flow corresponding to this heat load would be on the order of 1.5 to 2.0 lb per min. This flow is reached with decreasing temperature at 41.5°F or above. Although conclusive results were not obtained in the component test, this valve should regulate the cooling unit discharge temperature within the control band of 45 ±5°F.

TABLE I

PILOT CRYOGENIC HEATER BLANKET PERFORMANCE

Run		Electric Heater Power Input, Watts	Normal Oxygen Passages			Alternate Oxygen Passages			Nitrogen Passages		
			Inlet Temp, ^{0}F	Outlet Temp, ^{0}F	Flow, lb/min	Inlet Temp, ^{0}F	Outlet Temp, ^{0}F	Flow, lb/min	Inlet Temp, ^{0}F	Outlet Temp, lb/min	Flow lb/min
Each circuit tested separately:											
1	Circuit A	34.0	28.7	70.4	0.104	27.0	70.3	0.104	29.0	65.8	0.136
	Circuit B	34.0	28.0	74.2	0.104	26.1	72.0	0.104	28.1	64.8	0.136
2	Circuit A	34.0	39.0	81.0	0.100	46.0	89.0	0.101	48.0	84.0	0.136
	Circuit B	34.0	38.0	82.0	0.100	45.0	88.0	0.102	47.0	82.0	0.138
3	Circuit A	35.0	25.0	66.0	0.100	17.0	65.5	0.101	16.0	59.5	0.134
	Circuit B	35.0	21.0	64.0	0.100	15.0	61.5	0.103	14.5	54.0	0.133
Both circuits tested together:											
4		41.0	12.0	60.0	0.099	8.5	64.0	0.100	7.0	55.0	0.138
5		55.5	9.5	78.0	0.097	13.0	80.5	0.098	6.0	67.0	0.139
6		72.5	9.0	92.0	0.097	10.0	99.5	0.099	4.5	79.0	0.139

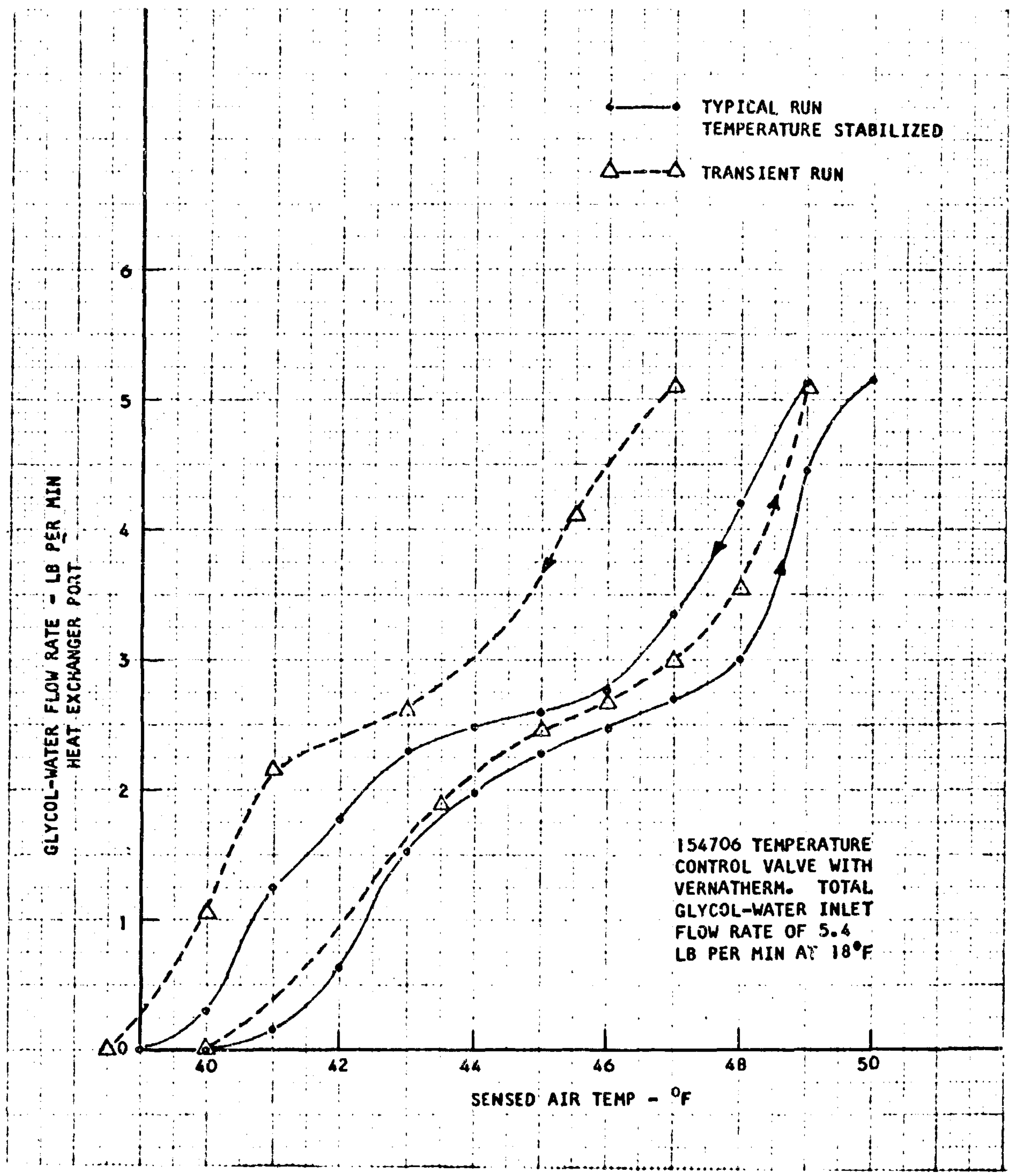


Figure 10. Pilot Temperature Regulating Valve Thermal Response Test

4. Air Sampler Temperature Stratification Test

a. Setup--The test setup is shown in the schematic diagram in Figure 11. The test setup consisted essentially of a source of regulated air flow at room temperature, and the apparatus to inject a smaller amount of high-temperature air upstream of the sampler. The introduction of the high-temperature air provides the temperature stratification of the total air mass that reaches the sampler, and the peripheral location on its introduction simulates stratification in various quadrants.

Temperature grids, which averaged the temperature at a cross-section, were installed downstream of the sampler in the main stream and in the sampler discharge.

Four temperature sensors were located immediately downstream of the sampler at right angles to each other to show the degree of temperature stratification at the sampler.

b. Procedure--Laboratory air at a mass flow of 36 lb per min, a temperature of 72°F, and a pressure of 30.85 in. Hg abs was established through the fan housing. The static pressure was adjusted at 6.0 in. H_2O gauge at the sampler. The sampler discharge valve was set to discharge a mass flow of 0.5 lb per min. All temperatures, pressures, and flows were recorded.

Hot laboratory air at a mass flow of 4.0 lb per min, a temperature of 200°F, and a pressure 31.80 in. Hg abs, was introduced into the main flow at a peripheral location in line with one of the four downstream temperature sensors. Again all temperatures, pressures, and flows were recorded. The hot laboratory air injector was positioned to a new location, again in line with a temperature sensor, and data was recorded. The above was repeated for all four positions as shown by the schematic in Figure 11.

c. Results--Data are tabulated in Table 2. The temperature stratification difference, ΔT, was determined by computing the temperature difference between the temperature sensor in line with the hot air and the three remaining temperature sensors.

Sampler error, expressed as degrees of error per degree of temperature stratification, was determined by dividing the temperature difference between the measured sampler discharge temperature and the average fan discharge temperature measured at the downstream temperature grid by the magnitude of temperature stratification (ΔT). Maximum stratification error was 0.1°F per degree of stratification, and occurred when the heated air was injected directly in line with the sampler discharge.

5. Fan Motor Performance

a. Procedure--With allowance for warmup, testing was initiated at a no-load condition, i.e., no torque restrained the rotor other than bearing friction, windage, etc. Maintaining a constant 200-v line-to-line input voltage, torque was progressively increased until the test was concluded in a locked rotor condition. Readings of amperes, watts, torque, rpm, and case temperature were taken for each increment of applied torque.

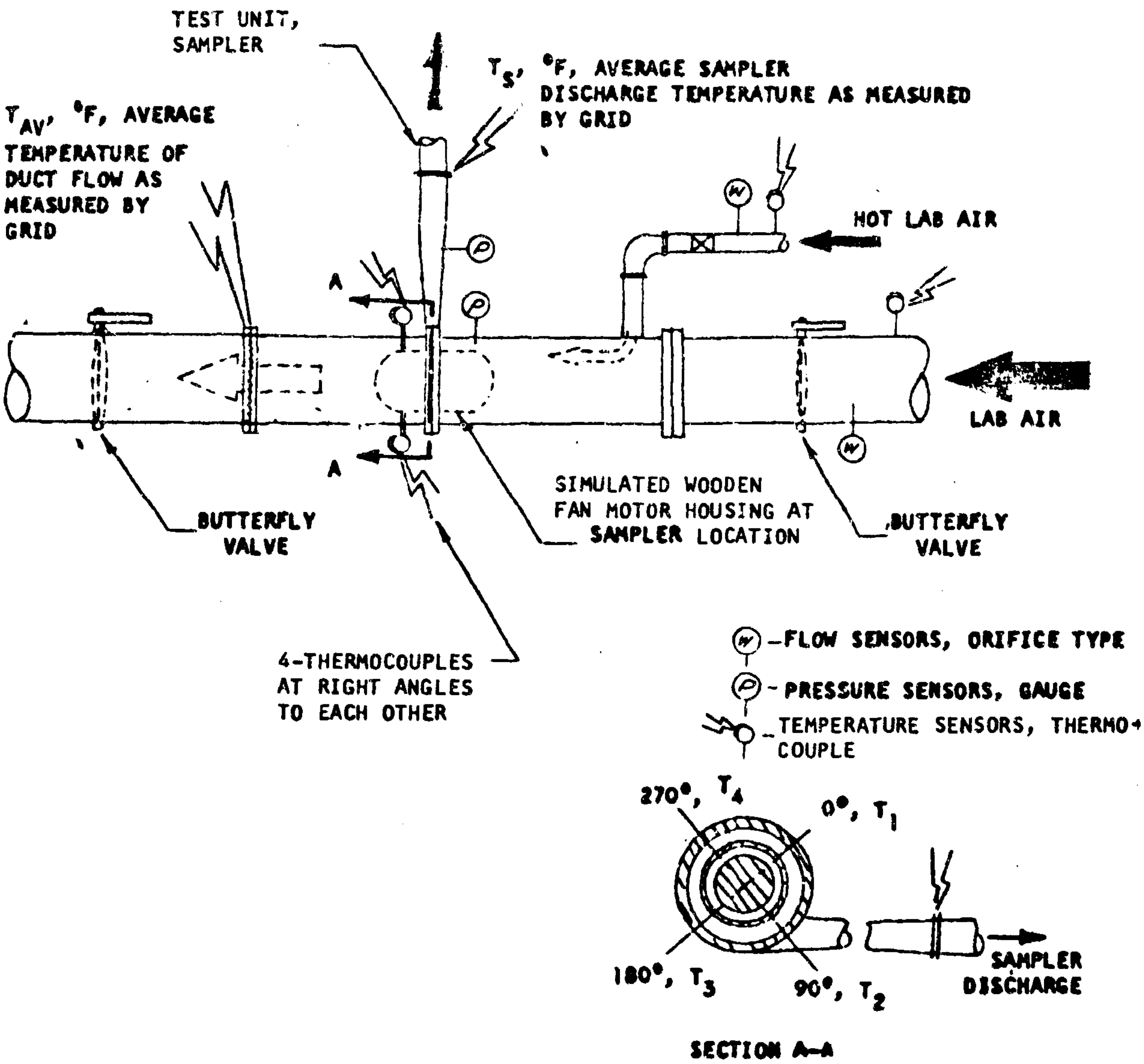


Figure 11. Sampler Stratification Test Setup

TABLE 2

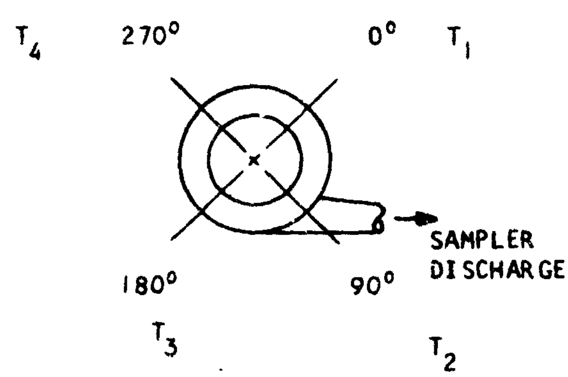
TEST RESULTS

T_1, °F	135	74	74	74
T_2, °F	74	139	74	74
T_3, °F	74	74	142	74
T_4, °F	74	74	74	133
T_{AV}, °F	85.1	85.5	85.0	85.2
T_s, °F	89.7	92.0	83.4	80.5
Stratification ΔT, °F	61	65	68	59
Sampler error $(T_s - T_{AV})$, °F	+4.6	+6.5	-1.6	-4.7
Sampler error, °F, per degree stratification $\frac{(T_s - T_{AV})}{\Delta T}$	+0.075	+0.100	-0.024	-0.080
Location of stratified air	0°	90°	180°	270°

NOTES

1. Stratified air crossing sampler slot is approximately 18 percent of the total flow.

2. See Figure 11 (test setup) for explanation of symbols.



b. Results--Results of the test are presented as performance curves in Figure 12.

6. Fan Performance Test

a. Procedure--The fan was operated at rated line voltage. Starting with the minimum flow restriction, the downstream restriction was increased incrementally to the fan blade stall condition. Flow, power, inlet and outlet temperatures, and pressures were recorded at each increment.

b. Results--The significant portion of the fan performance map is shown in Figure 13. The nominal sea level and altitude flows are indicated as dashed vertical lines. As shown, the fan meets the design point performance with some slight margin. Total pressure rise was calculated from static pressure readings.

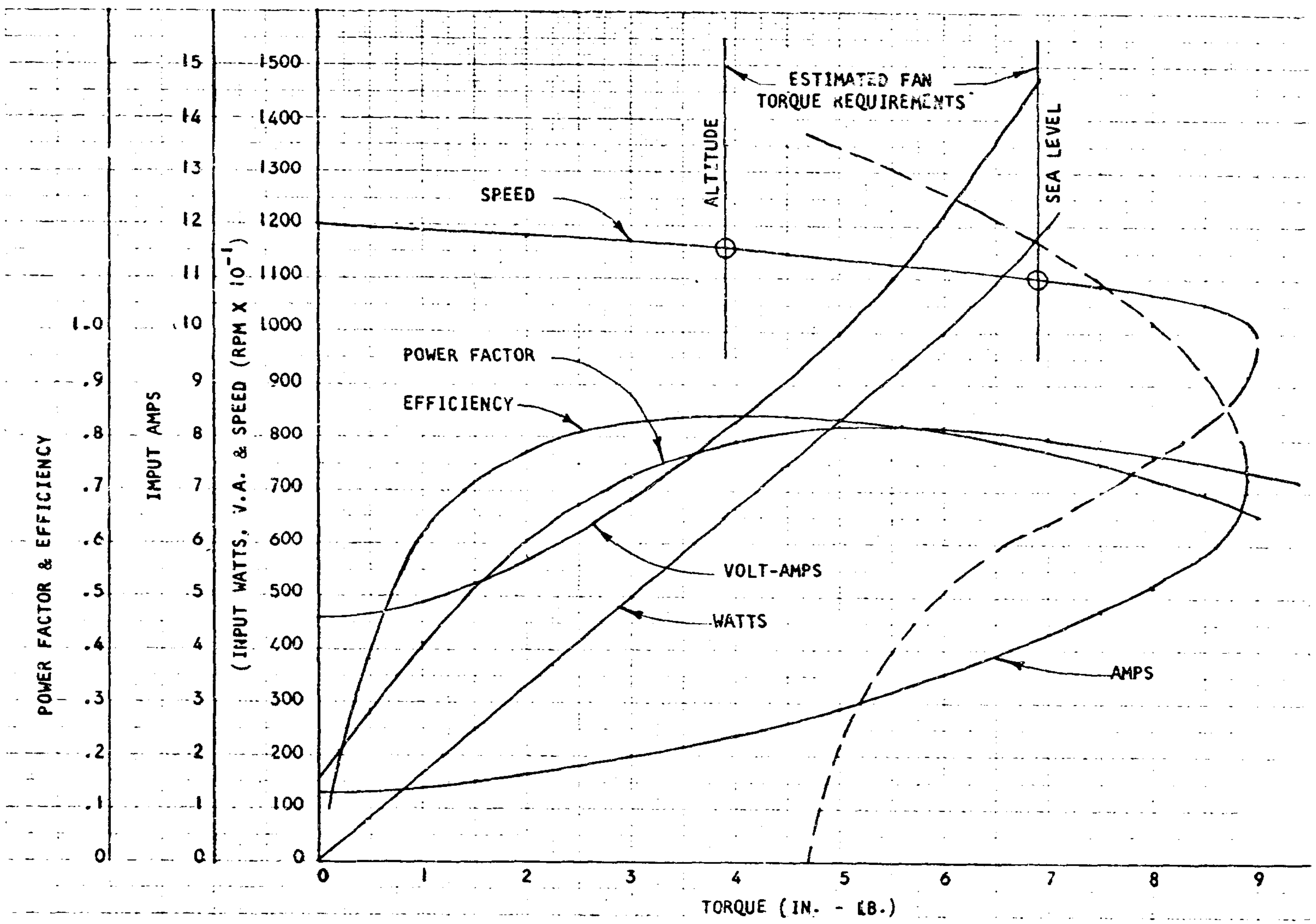


Figure 12. Pilot Fan Motor Performance

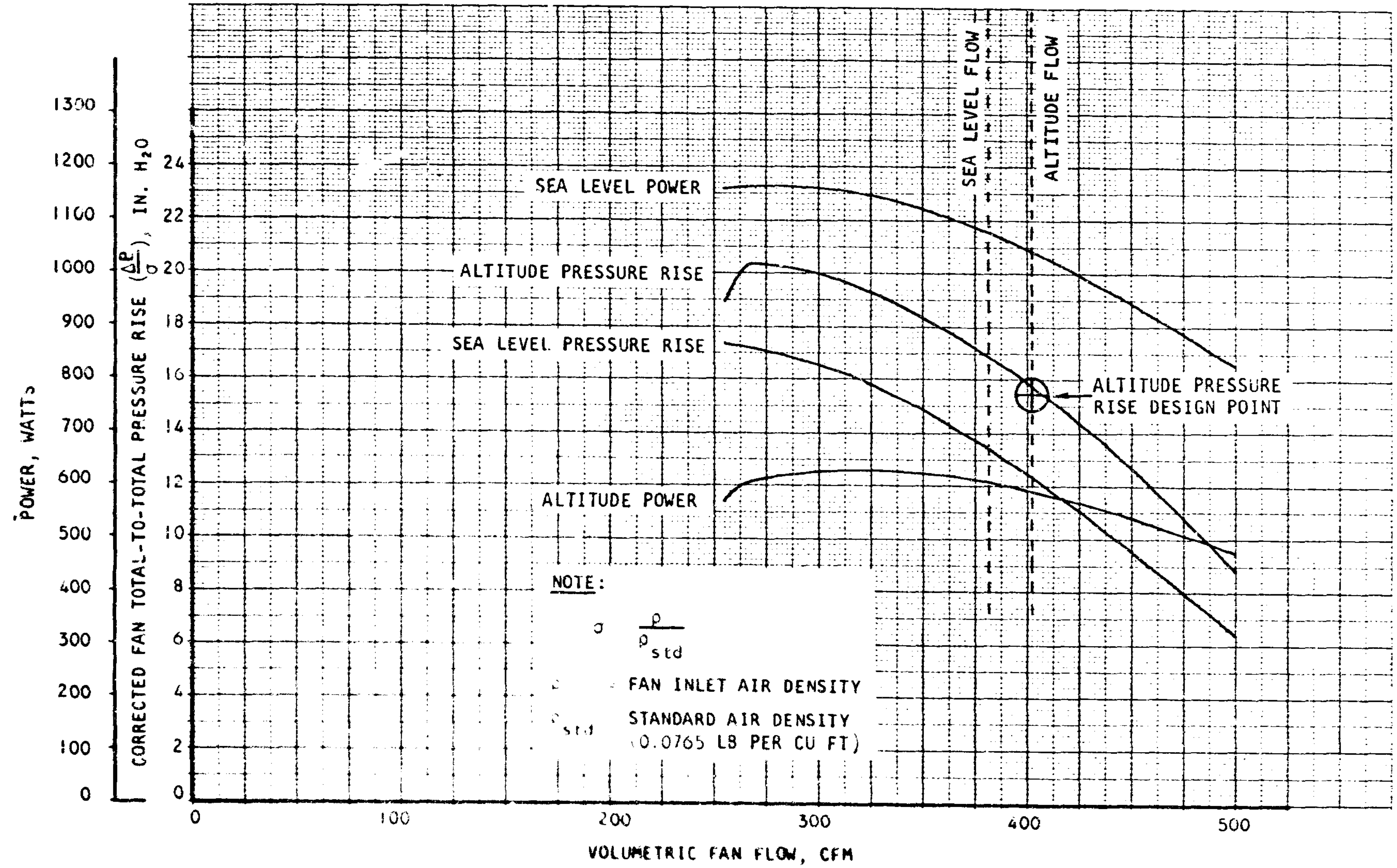


Figure 13. Pilot Fan Performance

THE -3 COOLER, EQUIPMENT COMPARTMENT COOLING UNIT 178390-1-1

Description

1. Cooling Unit Function

The equipment compartment cooler is designed to cool and circulate the atmosphere in the Dyna-Soar equipment compartment. It consists mainly of a heat exchanger, fan, and thermostatic control. The fan draws the compartment atmosphere, 100 percent nitrogen, through the heat exchanger, where the atmosphere is cooled by chilled glycol (a eutectic solution of ethylene glycol and water plus corrosion inhibitors, defined previously in this report). The compartment nitrogen-discharge temperature is regulated to 55°F by the thermostatic valve, which controls the proportion of total available chilled glycol flow that passes through the heat exchanger.

The cooling unit also warms the makeup nitrogen for the equipment compartment and preheats the makeup oxygen and nitrogen for the pilot compartment, which are supplied in liquid form from cryogenic storage vessels. The makeup gases are warmed by heat exchange with the compartment atmosphere in the cooling unit. When required, the equipment compartment makeup nitrogen is also heated by an electric heater. This heat exchanger and electric heater ensure that the nitrogen injected into the compartment is gaseous.

2. Physical Features

The physical features of the unit are shown in a series of three photographs in Figure 14. The unit was rotated 90 degrees about its flow axis toward the viewer in the successive views, as well as being turned around from end to end to show both the inlet and outlet faces. The unit pictured is the first completed to the present configuration under the present contract. The outline dimensions are shown in Drawing 178390, submitted separately.

Except for the rather imposing external framework, the arrangement of the components is much the same as for the -1 pilot cooler package described in the preceding section. The support frame was required in the -3 unit to provide support for the heat exchanger because the Dyna-Soar vehicle attachment points were at the fan discharge end only, resulting in a highly cantilevered structure.

In reading the ensuing descriptions of the principal components, it will be helpful to refer to both the series of photographs and the cross-sectional schematic, Figure 15. Note that the support frame has been omitted from the schematic for clarity.

In addition to the heat exchanger, fan, and temperature regulating bypass valve already mentioned, the three warning or indicator circuit devices and the cryogenic electric heater switch are also included in the following individual component descriptions. The warning devices are the airflow

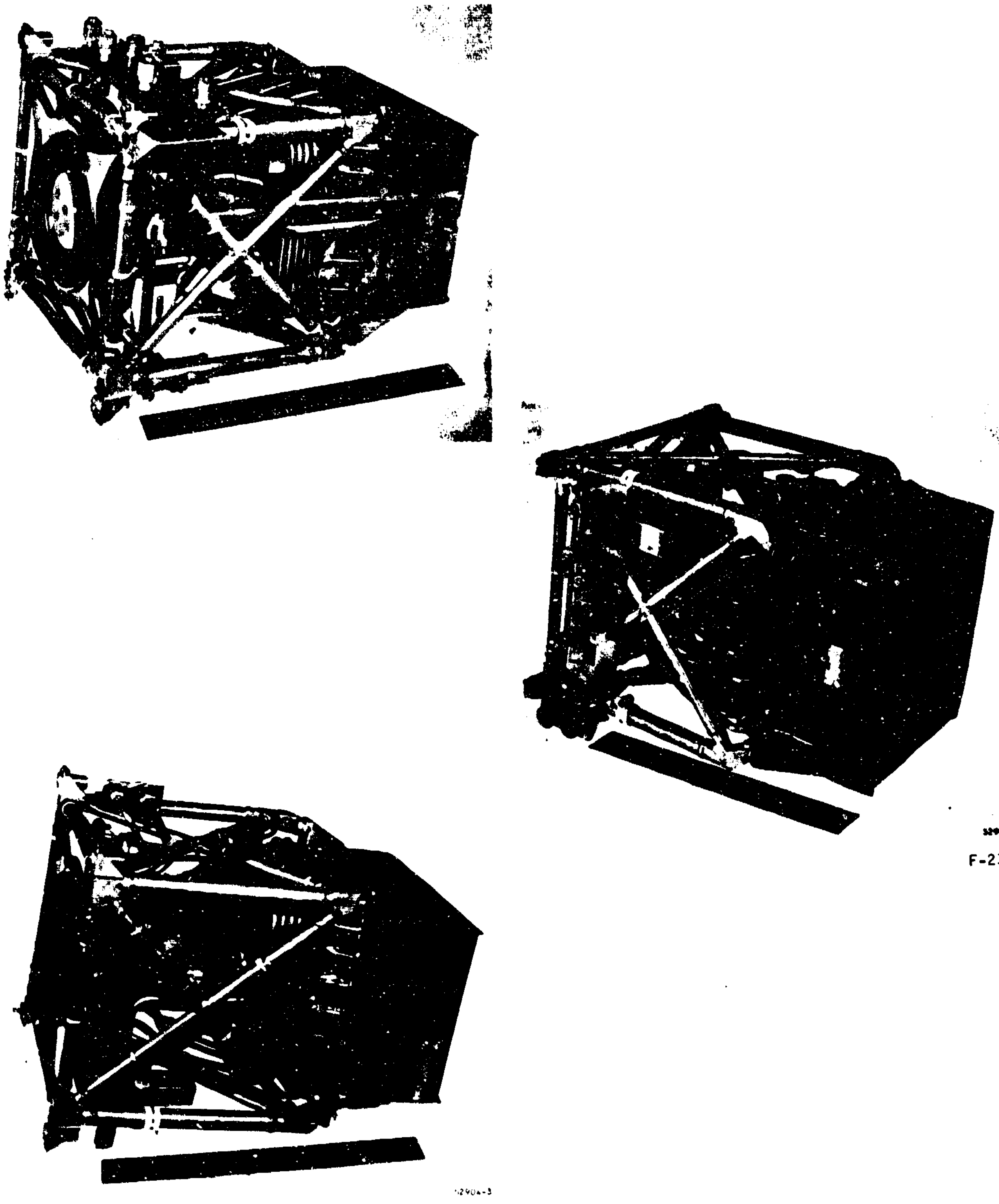


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Figure 14. Equipment Compartment Cooler

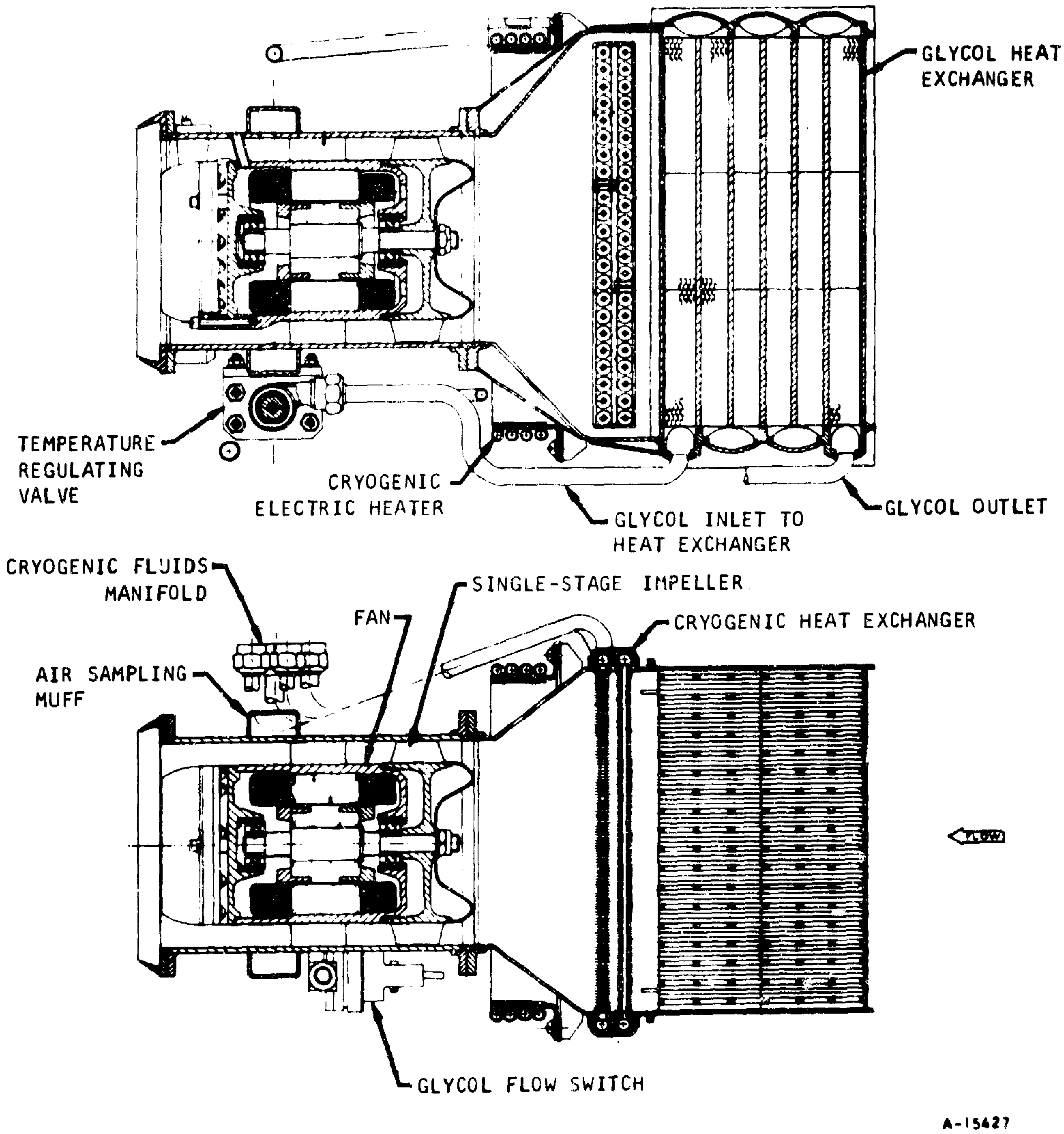


Figure 15. Cross-Sectional Schematic of Equipment Compartment Cooler

indicator, the air overtemperature indicator, and the glycol flow indicator. These devices all contain switches that activate the vehicle warning circuits, which are presumed to consist of indicator-light bulbs. The cryogenic electric heater switch consists of a thermal switch and a three-phase relay.

3. Heat Exchanger Assembly

The heat exchanger assembly comprises the glycol-to-air heat exchanger, the cryogenic (makeup gas) heat exchanger, the cryogen[illegible]ter, the transition section (to mate with the fan), related plumbing [illegible] and the four mounting points for attachment to the support frame.

a. Glycol Heat Exchanger--The glycol-to-nitrogen, or simply the glycol, heat exchanger is of all-aluminum, brazed-and-welded, plate-fin construction. It has six glycol passes and a single, straight-through air pass in a cross-counterflow arrangement. The glycol tubes are single-sandwich, 0.075 in. high, while the air passages are triple-sandwich construction, using three layers of 0.1-in.-high fins, for a total height of 0.3 in. The tubes next to the side plates are reduced to a double sandwich on one side and a single sandwich on the other side. There are 18 glycol tubes per pass, and 19 air tubes per pass, counting those adjoining the side plates. The heat exchanger inlet face has a screen to remove any particles which might be large enough to damage the fan, as shown in Figure 14.

b. Cryogenic Heat Exchanger--The cryogenic heat exchanger is located in the transition section between the glycol heat exchanger and the fan. It consists of two banks of finned tubes extending across the airstream between tubular headers. It is made entirely of aluminum and is joined by welding. The fins are integral with the tubes, being formed by machining larger-OD tubes.

The heat exchanger has a separate circuit for each of the four makeup circuits, equipment nitrogen, pilot nitrogen, pilot normal oxygen, and pilot emergency oxygen. Each bank warms one nitrogen and one oxygen circuit. Each oxygen circuit contains eight tubes arranged in four passes, with two tubes per pass. Each nitrogen circuit contains 14 tubes arranged in four passes, so that two passes have three tubes each, and two passes have four tubes each. All tubes are 0.1 in. in ID, with a minimum wall thickness after machining of 0.015 in.

c. Electric Heater--An electric heater is included as an adjunct to the cryogenic heat exchanger; in the event of compartment fan failure, the heater, which is turned on automatically by a temperature switch and relay, would provide sufficient heat to vaporize the cryogenic nitrogen. The heater is in the form of a silicone rubber heating strip, cemented along one side of a metal backing plate that nests four-compartment nitrogen tubes side-by-side for a running length of about 28 in. downstream of the cryogenic heat exchanger. The blanket contains a three-phase resistance wire circuit laminated in silicone rubber. The tube nest is looped around the transition section, with the heater blanket on the inside surface of the

loop. The outside of the heater loop is easily distinguished in the three-view photo series by the four parallel tubes. The nitrogen flows through the tubes in parallel. Only the equipment compartment nitrogen passes through the electric heater.

4. Fan

The fan is a single-stage, axial-flow fixed-geometry, ducted fan directly driven by a three-phase, 400-cps, 115/200-v a-c, moderate-slip, two-pole induction motor. The two impellers are mounted at opposite ends of the motor. The motor and impeller are centerline-mounted in a cylindrical duct, or housing. Fixed-geometry deswirl vanes are provided in the housing and serve as the motor support structure. The fan arrangement is shown clearly in the cutaway schematic, Figure 15.

The inlet end of the fan housing has a bolt flange for attachment to the transition section of the heat exchanger assembly. The discharge end of the fan housing has a rubber sealing lip for mounting the unit against a bulkhead opening.

The housing contains air sampling passages to divert a small portion of fan discharge air through the thermostatic valve. To ensure that this sample is representative of average discharge temperature, eight bleed slots are spaced 45 degrees apart circumferentially in the housing downstream of the second-stage deswirl vanes. The slots lead into a common mixing muff, or plenum, which, in turn, opens directly into the thermostat cavity of the temperature regulating valve. From the valve, the air sample exhausts to the ambient (equipment compartment) atmosphere. The clearest illustration of the sampler is shown in cross-sectional View A-A of Figure 15. The sampling-air flow does not exceed 2 percent of the total flow.

The fan housing not only contains the fan itself, but provides a housing for the temperature regulating valve, the air flow indicator, and the over-temperature indicator. The valve and the connectors are external, while the warning indicators are buried inside the fan diffuser cone. The discharge end of the housing is slipped into a ring in the support frame, which provides radial support for that end of the fan-heat exchanger combination.

All structural parts of the fan and housing are made of aluminum.

5. Temperature Regulating Valve

The -3 temperature regulating valve is identical to the -1 temperature regulating valve, with the exception of fluid port locations and the temperature calibrations. The temperature calibrations are listed in the respective performance paragraphs. The description of the working mechanism of the -1 valve is fully applicable to the -3 valve.

6. Air Flow Indicator

The air flow indicator is the same as that described for the -1 package, except for calibration. The unit is mounted inside of, and forms a part of the fan diffuser cone. The portion of the exterior which forms the diffuser fairing appears in Figure 14. The calibration screw is visible in the photograph at the center of the fairing.

7. Nitrogen Overtemperature Indicator

This indicator (switch) is identical to that described for the -1 package, with the exception of calibration, which is given under the Operation and Assembly heading. The switch is mounted inside of, and in intimate contact with, a thin-wall portion of the diffuser cone. The heads of its two mounting screws are visible in Figure 14.

8. Glycol Flow Indicator

The glycol flow indicator is identical to that described for the -3 package.

9. Heater Switch and Relay

The switch and relay operate together to control the cryogenic electric heater in response to the nitrogen temperature at the heater outlet. The switch turns the actuating current to the relay solenoid on or off, and the relay turns the current to the heater on or off in response to the switch position. When the switch is on, the heater is on, and vice versa.

The switch is a commercially available thermal switch manufactured by United Controls Corporation. It is a single-pole, single-throw, snap-action switch, suitable for operation on either 28-v d-c or 115-v a-c. It is calibrated by the manufacturer to close on decreasing temperature at -22.5°F and to open on increasing temperature at 105 $\pm 5^{\circ}$F. The switch is mounted in an aluminum well in the heater outlet manifold.

The relay, a commercial product of Pacific Relay, Inc., provides a four-pole, double-throw 28-v d-c or 115-v a-c armature operated by a 28-v solenoid. Only three of the four poles are used, one for each phase, with the ground wire permanently connected to the heater. The relay is used in single-throw mode only, with one set of contacts left unconnected.

Assembly and Operation

The cooling unit is designed for operation in a compartment atmosphere ranging from sea level atmosphere to pure nitrogen. The atmosphere for flight conditions is nitrogen, at 10.0 psia, conforming to Specification MIL-P-27401A. Air or 100-percent nitrogen may be used satisfactorily as the compartment atmosphere for test purposes.

It may be necessary to use relatively dry compartment atmosphere to prevent frost accumulation on the cryogenic heat exchanger. It is recommended that the compartment atmosphere dew point not exceed 20°F. The frosting phenomenon is described and shown in a series of photographs, under Performance, later in this section.

The cryogenic makeup circuits are designed for operation with pure oxygen and nitrogen conforming to Specifications MIL-O-27210 and MIL-P-27401A, respectively. However, heat transfer properties are sufficiently similar so that nitrogen may be used in the oxygen passages for safety during tests. For system tests in which it is necessary only to simulate the cryogenic cooling effect, any convenient fluid may be used, with flow rates or temperatures, or both, adjusted accordingly.

The glycol fluid to be used should be an aqueous ethylene glycol solution with inhibitors prepared as described for the -1 unit.

The fluid ports are defined by Envelope Drawing SK 44513, submitted separately. The glycol fittings on the -3 unit are standard MS flareless bulkhead fittings instead of the special double-seal Mil Flo fittings specified by the original contractor. At the time parts were procured, the appropriate Mil Flo fittings were not available, so standard fittings were to be used in the interim. MS-to-Mil Flow adapters are now available from the Mil Flo Corporation, Dayton, Ohio.

The fittings for the cryogenic circuits are also standard MS fittings. The cryogenic plumbing arrangement is shown and the cryogenic gas ports are identified in Figure 16.

The fan and electric heater each require 115/200-v, three-phase, four-wire, 400-cps electric power. The electrical connectors are defined in Drawing SK 45513.

The indicator switches and the heater switch and relay are designed to operate with 28-v d-c and with an external load not to exceed 5 amp for each switch. For test purposes, any convenient voltage can be used, provided the current does not exceed the rated load. AiResearch frequently uses a 6-v battery with incandescent lamps for test purposes.

The electrical schematic is shown on the wiring diagram label which is furnished on the unit itself.

The cooling unit is shipped with the glycol passages drained, flushed with solvent, and dried with clean air or nitrogen. Therefore, special attention should be given to removal of trapped air during filling the glycol loops.

The cryogenic passages are purged with dry nitrogen before shipment and require no special precautions in their operation.

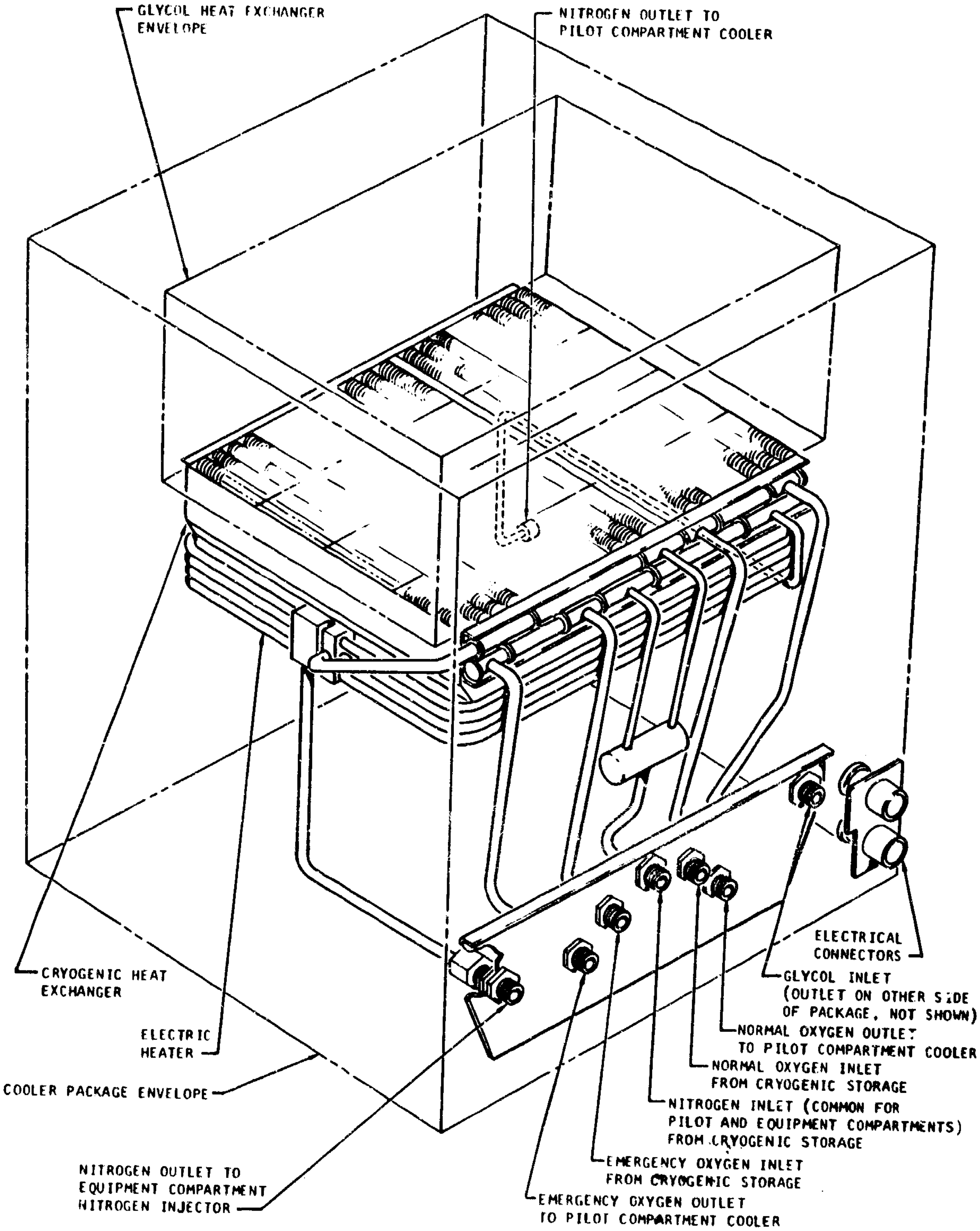


Figure 16. Cryogenic Plumbing Arrangement

The following switch points are listed as an aid in monitoring the warning circuits.

Fan Flow Indicator:

No flow increasing to 85 percent flow--indicator on
85 to 95 percent flow--switch point, increasing flow
Above switch point--indicator off
77 to 70 percent flow-switch point, decreasing flow
Below 70 percent flow--indicator on

Air Overtemperature Switch:

Increasing temperature to 69°F--indicator off
69°F to 75°F--switch point, increasing temperature
Above switch point--indicator on
75°F to 65°F--switch point, decreasing temperature
Below switch point--indicator off

Glycol Flow Indicator:

No flow to 2 lb per min--indicator on
2 to 2.5 lb per min--switch point, increasing flow
Above switch point--indicator off
2.5 to 1.5 lb per min--switch point, decreasing
Flow below switch point--indicator off

Cryogenic Electric Heater Switch:

Room Temperature to -20°F--heater off
-20 to -25°F--switch point, decreasing temperature
Below -25°F--heater on
Increasing temperature -25 to +100°F--heater on
100 to 110°F--switch point, increasing temperature
Above 110°F--heater off
Decreasing to room temperature--heater off

Performance

The performance of the -3 cooling unit is summarized in the following listed design requirements.

Applied Conditions

Maximum heat load	350 Btu per min
Minimum heat load	60 Btu per min

Maximum rate of compartment nitrogen inlet temperature change	
Increasing temperature	15^{o}F per min
Decreasing temperature	5^{o}F per min
Glycol flow range	
Normal	4.5 to 5.8 lb per min
Failed conditions	4.0 to 5.8 lb per min
Design point	5.43 lb per min
Glycol inlet temperature	5^{o}F to 24^{o}F
Cryogenic fluid flow	
Oxygen	
Normal	0.1 ±0.01 lb per min
Alternate	0.1 ±0.1 lb per min
Emergency	0.2 ±0.02 lb per min
Nitrogen	
To pilot compartment	0.13 ±0.1 lb per min
To equip compartment	0.14 ±0.1 lb per min
Cryogenic fluid inlet temp	
Oxygen	-157^{o}F and 46 percent quality to -220^{o}F and 31 percent quality
Nitrogen	-205 to -258^{o}F, saturated liquid
Compartment nitrogen flow (altitude)	18.3 lb per min minimum
Corresponding sea level flow	26.5 lb per min (approx)
Static pressure rise	
At 10.0 psia	4.5 in. H_2O minimum
At 14.7 psia	3.0 in. H_2O minimum
Compartment nitrogen outlet temperature	55 ±5^{o}F
Fan power consumption	
Altitude	550 w maximum
Sea level	865 w maximum

Cryogenic gas outlet temperature	
To equipment compartment	$-25^{\circ}F$ to $+72^{\circ}F$
To pilot compartment	$-15^{\circ}F$ to $+60^{\circ}F$
Cryogenic gas pressure drop	
All circuits	5 psi maximum
Cryogenic heater power consumption	
ac	375 ±20 w
dc (relay holding)	3 w maximum

The fluid passages have been designed to withstand the following pressures.

	Maximum Operating, psig	Proof psig	Burst psig
Glycol	110	165	275
Oxygen (flow conditions)	300	450	750
(no flow)	1506	2260	3760
Nitrogen	230	345	575

The high oxygen proof pressure required for the "no flow" condition is to accommodate a peculiarity of the Dyna-Soar system in which cold, partially liquid oxygen could become trapped downstream of the pressure regulator. The oxygen passages were designed for a proof pressure of 3390 psig, a strength obtained in part by heat treating the cryogenic heat exchanger to the T6 condition. For the units delivered under the present contract, it was decided to omit the heat treatment so as not to risk tube cracking during quench because no replacements were available for the special finned tubes. It was felt that the 2260 psig proof pressure now offered was sufficiently in excess of present needs.

Other significant features of the cooling unit are:

Weight: Dry 24.76 lb (calculated)
Wet 27.36 lb (calculated)

Life: 2000 hr, with fan servicing at 500 hr intervals

The set points of the warning switches are presented in the paragraph on assembly and operation above.

Detailed performance of the glycol heat exchanger, fan motor, and fan are presented in the following paragraphs.

I. Equipment Glycol Heat Exchanger Performance Test

a. Procedure--The heat rejection test was run at the following conditions (total of 16 points):

	Compartment Nitrogen Passages (Air)	Glycol Passages
Inlet temperature	131 $\pm 3^{\circ}F$	18.3 $\pm 3^{\circ}F$
Inlet pressure	14.7 ±1 psia	40 ±5 psig
Flow, lb per min	10 ±2, 24 ±2, 32 ±2, 18.6 ±0.5	2.0 ±0.1
	10 ±2, 24 ±2, 32 ±2, 18.6 ±0.5	4.0 ±0.1
	10 ±2, 24 ±2, 32 ±2, 8.6 ±0.5*	5.43 ±0.01*

*Design point flows.

Isothermal pressure drops across the heat exchanger air and glycol passages were conducted as a separate phase of the test and covered the same range of flows as the heat transfer tests.

b. Results--The pressure drop and heat transfer test results are presented in Figures 17, 18, and 19.

Figure 17 shows the heat transfer performance in terms of UA. The UA is plotted as a function of air flow for a family of glycol flows, including the system design glycol flow of 5.4 lb per min. The AiResearch design point is plotted on the curve for comparison. At the sea level design flows of 18.6 lb per min nitrogen and 5.4 lb per min glycol, the UA is 13.5 Btu per min-$^{\circ}F$, which exceeds the calculated UA of 12.2 Btu per min-$^{\circ}F$.

The heat transfer test results as obtained with air are applicable to performance with nitrogen, because of the similar heat transfer properties of the gases The results shown may be slightly conservative because of the slightly higher specific heat of nitrogen.

Figure 18 shows the glycol pressure drop as a function of glycol flow at a temperature of $18^{\circ}F$. At the nominal system glycol flow of 5.43 lb per min, the pressure drop is 13.7 in. Hg.

Figure 19 shows the air pressure drop as a function of flow at $70^{\circ}F$ and sea level discharge pressure. The air density ratio (σ) of the test air was essentially 1.0; therefore, the ordinate of the curve can be considered to be $\sigma\Delta P$ and ΔP. The AiResearch design point $\sigma\Delta P$ is plotted on the curve for comparison. At the design flow of 18.6 lb per min, the air pressure drop was 0.88 in. H_2O.

The actual compartment gas pressure drop during operation with nitrogen may be very slightly higher than the results recorded with air, but preliminary fan tests indicate that the heat exchanger pressure drop is completely compatible with the fan performance.

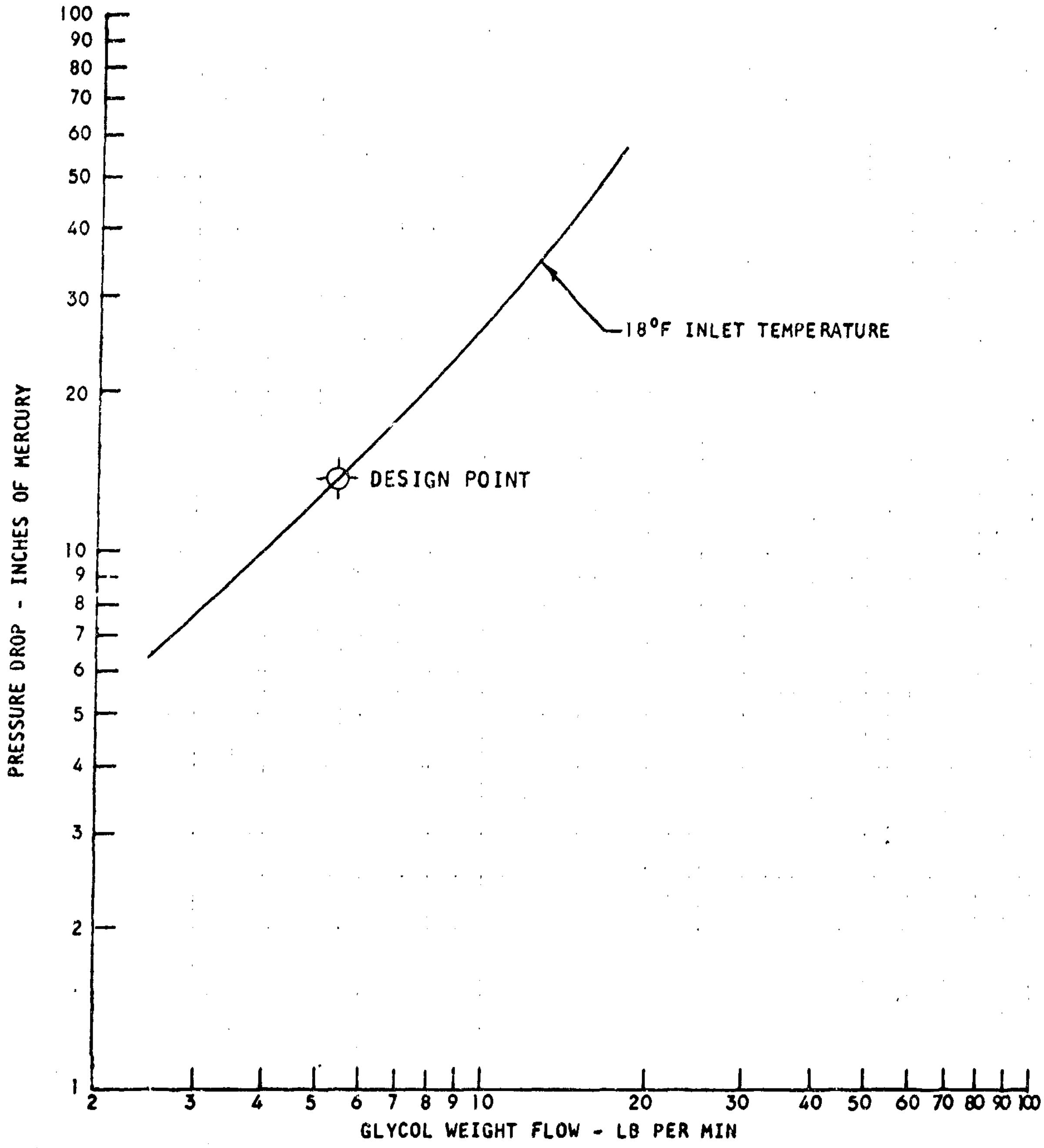


Figure 17. Glycol Heat Exchanger Isothermal Glycol-Pressure Drop

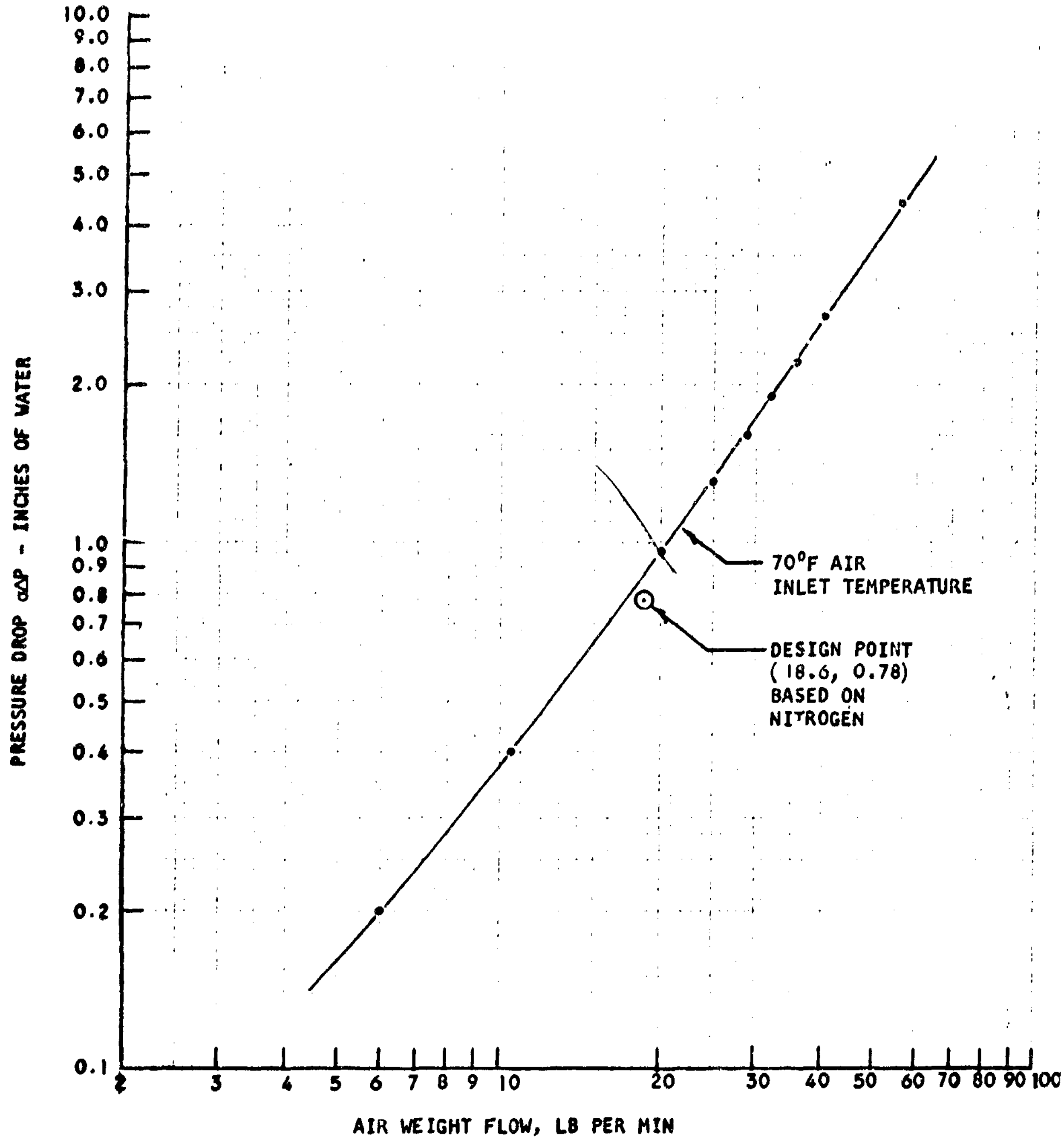


Figure 18. Glycol Heat Exchanger Isothermal
Air-Pressure Drop

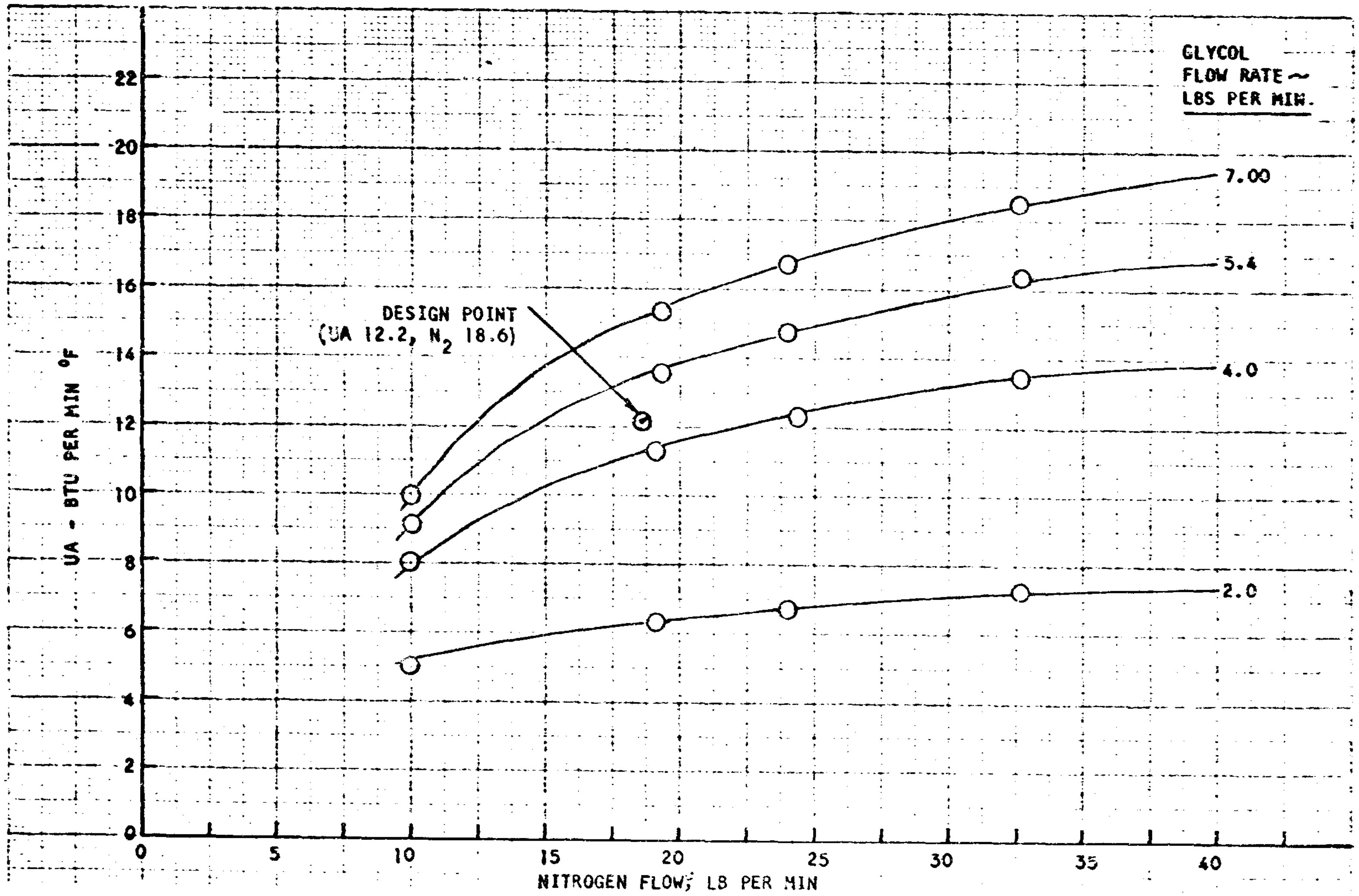


Figure 19. Glycol Heat Exchanger Heat Transfer Performance

2 Temperature Regulating Valve Thermal-Response Test

The test is described under the - package The results of this test are applicable to both the -1 and -3 units because the valves are identical with the exception of port locat on and thermostat calibration.

3. Air Sampler Temperature Stratification Test

This test is described under the -1 package. The test is applicable to both the -1 and -3 units on the basis of similarity of the fan housings.

4. Fan Motor Performance

a. Procedure--With allowance for warm-up, testing was inditiated at a no-load condition, i e., no torque restrained the rotor other than bearing friction, windage, etc Maintaining a constant 200-v line-to-line input voltage, torque was progressively increased until the test was concluded in a locked rotor condition. Readings of amperes, watts, torque, rpm and case temperature were taken for each ncrement of applied torque.

b. Results--Results of the test are presented by performance curves shown in Figure 20.

5. Fan Starting Transient Test

a. Procedure--The motor (with fan) was placed on a bench to obtain an unrestricted fan discharge at ambient temperature and pressure conditions.

With the test unit motor turned off and the oscillograph operating at speed of 16 in. per second the test motor was turned on. The test d until the motor reached steady-state operation.

Current and voltage in one phase of the motor were recorded and were taken to be representat ve of the other two phases. The starting time was derived from the oscillograph tape by measurement of current trace length from start point at the po nt where current reached a minimum and steady value.

b. Results--The results of the starting transient test are shown in Figure 21. The curve was derived from the current trace made on oscillograph tape. The time required for the motor to reach operating speed from a dead stop was 3.25 sec. The maximum starting current was 12.4 amp, and the steady state operating current was 2.35 amp.

6. Fan Performance Test

a. Procedure--The fan was operated at rated line voltage. Starting with the minimum flow restriction, the downstream restriction was increased incrementally to the fan blade stall condition. Flow, power, and inlet and outlet temperatures and pressures were recorded at each increment.

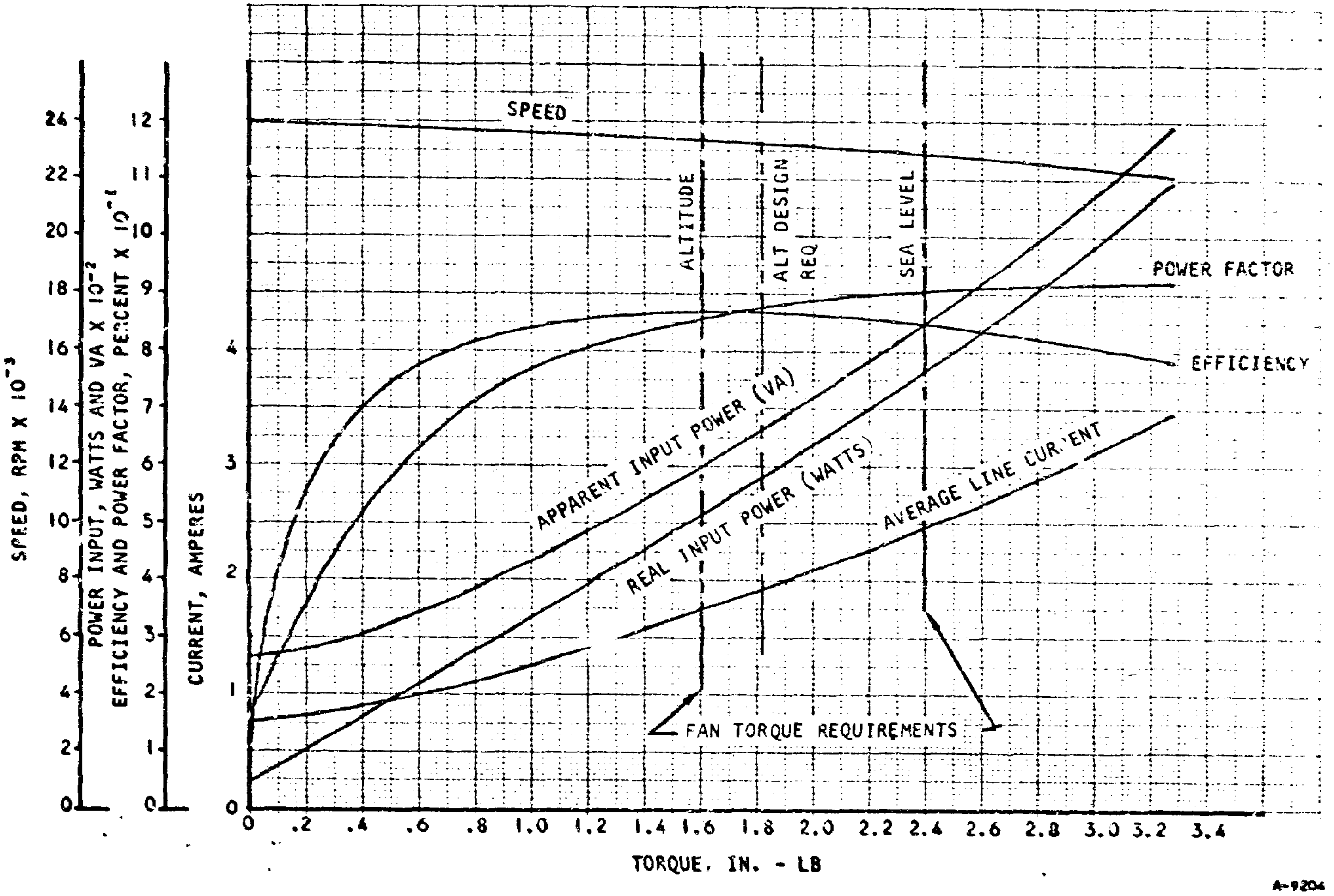


Figure 20. Fan Motor Performance

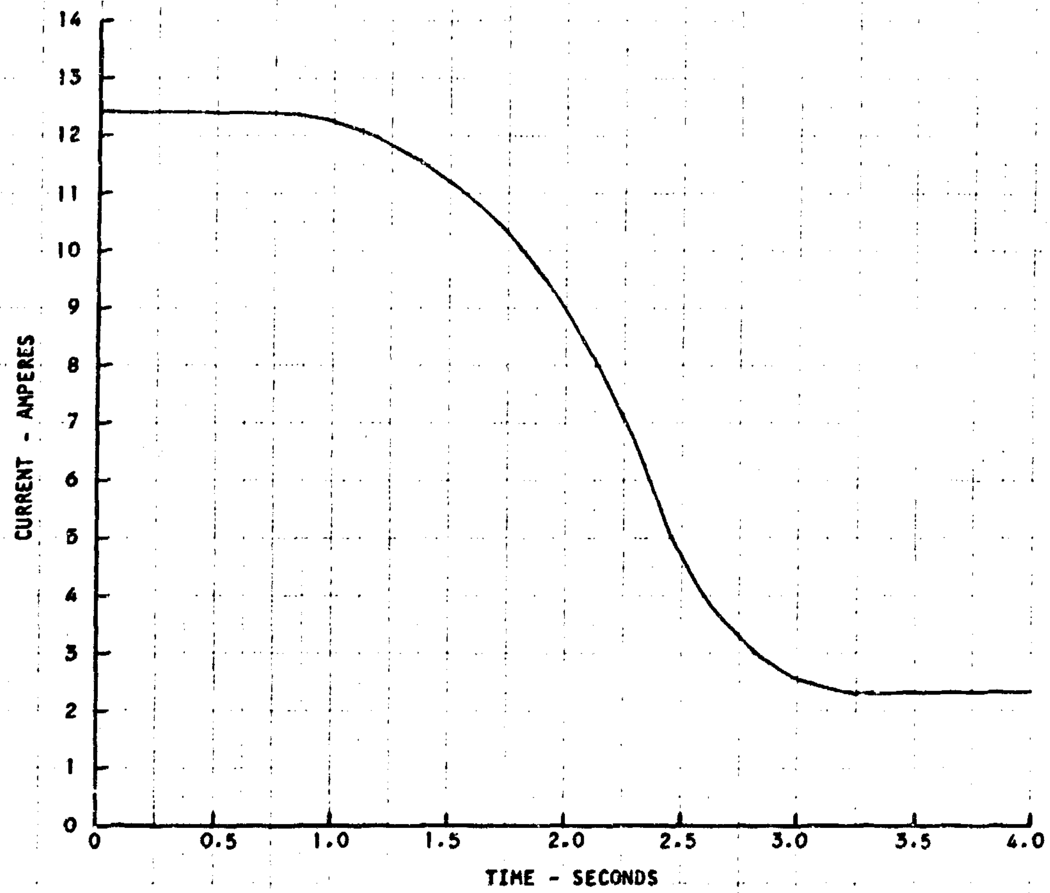


Figure 21. Fan Motor Starting Transient

b. Results--The significant portion of the fan performance map is shown in Figure 22. The nominal sea level and altitude flows are indicated by dashed vertical lines. As shown, the fan meets the design point performance with some slight margin. Total pressure rise was calculated from static pressure readings.

7. Cryogenic Heat Exchanger Dew Point Test

This test was conducted to determine the -3 unit's tolerance for moisture in the equipment compartment atmosphere. Moisture collects and freezes on the finned tubes of the cryogenic heat exchanger because the tubes are almost entirely below freezing. This problem is peculiar to the -3 unit because, in the -1 pilot unit, the tubes are largely above freezing.

a. Test Setup--The cryogenic test heat exchangers were installed in a test duct as shown in Figure 23. The emergency and normal oxygen heat exchangers were included in the test setup although no liquid oxygen was introduced through the oxygen section. Liquid nitrogen was introduced through the nitrogen section of the nitrogen cryogenic heat exchanger test unit. After passing through the heat exchanger, the nitrogen was warmed in an ambient-air heat exchanger, and flow was measured through a calibrated orifice plate.

Air was supplied to the test unit from a high-pressure warm air source. Supply-air temperatures were maintained at the desired level by bypassing a cooling turbine. Correct upstream pressure was obtained by adjustment of a bleed valve. Air temperature upstream of the test heat exchanger was monitored with three dual thermocouples radially spaced at 90 degree angles. Test unit pressure drop was observed with a draft gauge using three static pressure taps radially spaced at 90 degree angles, both upstream and downstream of the test unit. Inlet-air total pressure traverses of the heat exchanger were observed with a draft gauge and a movable total pressure pickup located 1 in. from the inlet face of the heat exchanger. Incoming-air mass flow was monitored through a calibrated orifice plate.

Dew point of the test air was observed with a dew-point indicator that obtained inlet air samples upstream to the test unit. The dew point was maintained at the desired level by the introduction of distilled water upstream of the cooling turbine.

b. Procedure--Testing was conducted in continuous steps, with all parameters except dew point held constant. Inlet air conditions were held to the following values:

Inlet temperature	$43.9\,^{+0}_{-3.6}\ ^{\circ}F$
Inlet pressure	$14.65\,^{+0.01}_{-0.00}$ psia
Flow	14.0 ± 0.3 lb per min

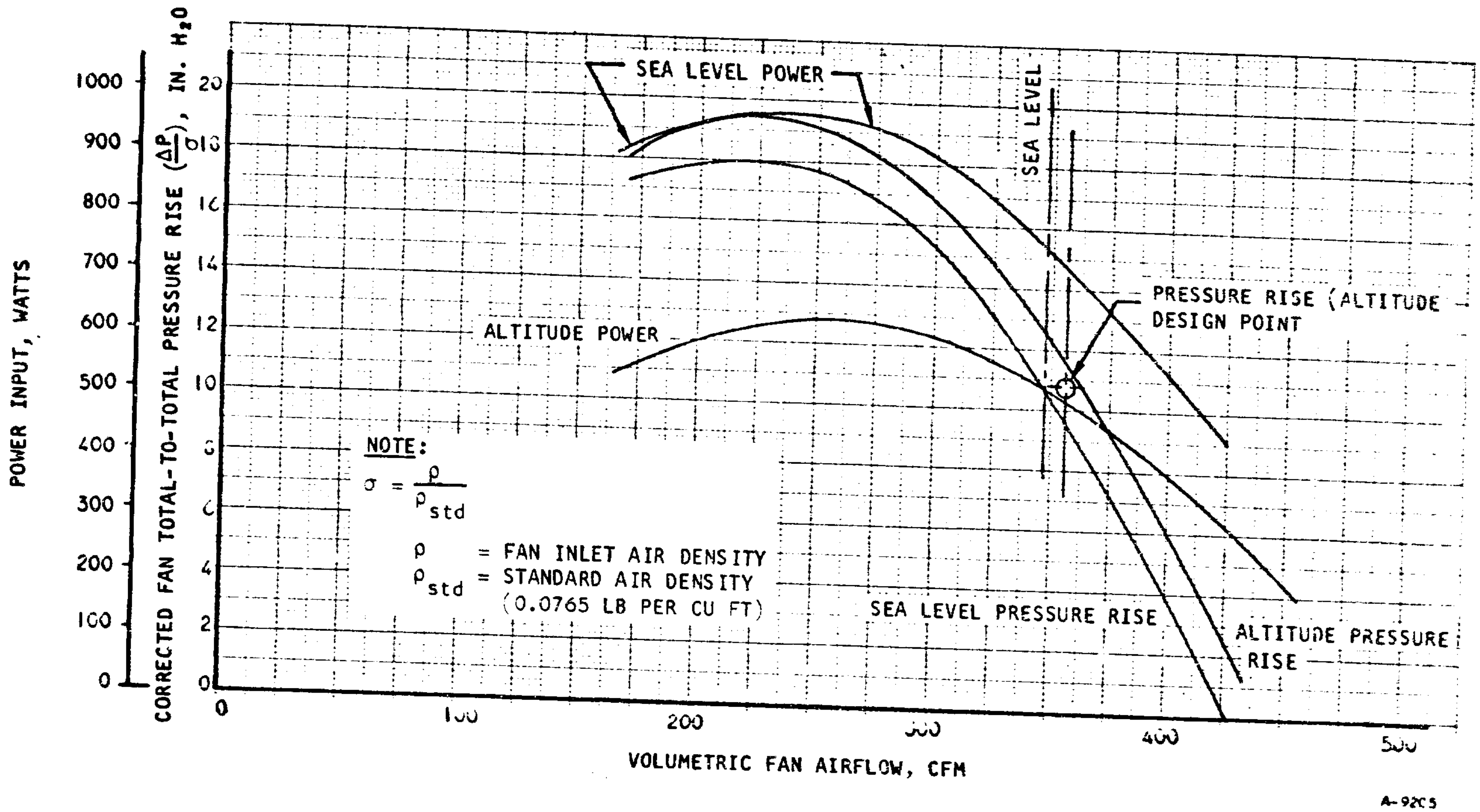


Figure 22. Fan Aerodynamic Performance

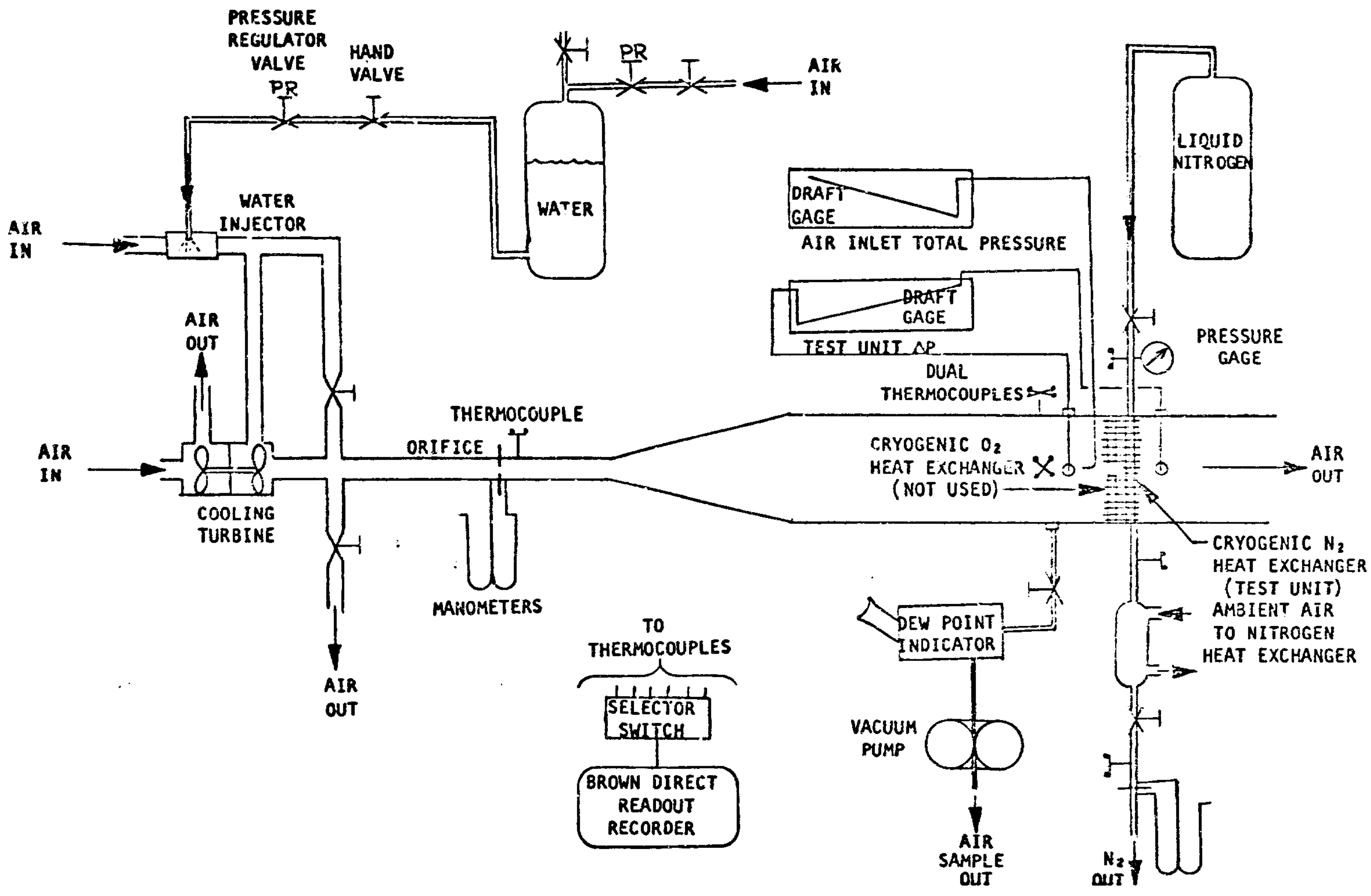


Figure 23. Dewpoint Test Setup

Liquid nitrogen conditions were held at the following values:

Inlet temperature	$305 \, {}^{+1}_{-4} \, {}^{\circ}F$
Inlet pressure	38.15 ±1.0 psia
Flow	0.14 +0.01 lb per min

Dew points at 0, 5, 10, 15 and 20°F were established by increasing the dew point temperatures in continuous steps. Beginning with 0°F dew point, frost accumulation was allowed to progress until a steady state condition of frost formation on the test unit was reached. The supply-air dew point was then increased in 5°F increments up to 20°F, with frost formation stabilization at each dew-point level. The time required for establishment of steady-state frost patterns after each dew point change was in the order of 30 min.

A total pressure probe traverse was made at the test heat exchanger inlet. Eight equally spaced points were included in each traverse. The traverse was made in a direction perpendicular to the test heat exchanger tubes and at a point of 1 in. upstream to the test unit. Each dew-point run was followed by a total pressure traverse. At the finish of the 20°F-dew-point run, one total pressure traverse was made downstream of the test heat exchanger.

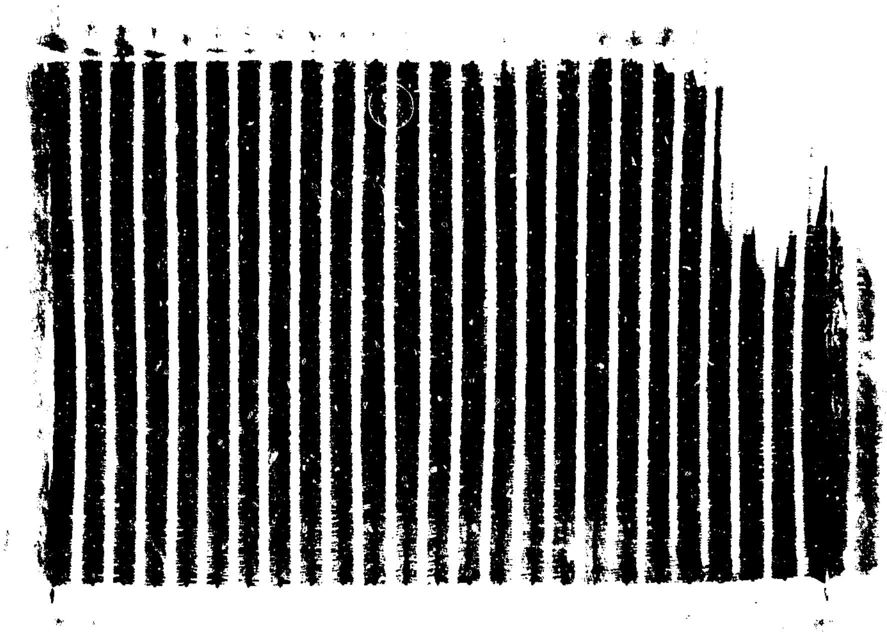
Thawing characteristics of the test heat exchanger also were investigated. Ice was accumulated on the heat exchanger by the introduction of air at a 15° dew point and allowing frost stabilization. The liquid nitrogen flow through the heat exchanger was then discontinued.

c. Results--During the dew-point test run, the pressure drop across the air side of the test heat exchanger increased from 0.11 in. H_2O at the 0.0°F dew-point run to 0.24 in. H_2O at the 20°F dew-point run as a result of ice formation on the cooling coils. The ice formation at the beginning and end of each dew-point run is shown in Figures 24 through 28.

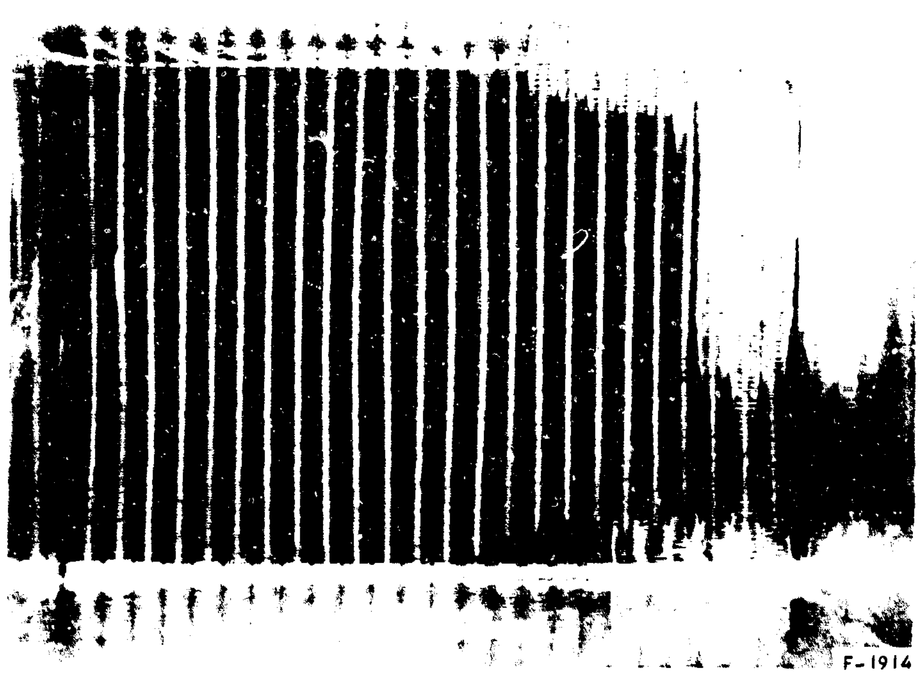
The total pressure profiles taken upstream to the test unit were essentially constant across the entire face of the heat exchanger for all test points, regardless of frost formation. The velocity profile taken downstream of the test heat exchanger showed a complete loss of total pressure over approximately half of the heat exchanger face. As may be seen in Figure 28, a substantial amount of frost accumulated in the duct downstream of the test unit. At the higher dew-point temperatures, ice-laden vapor appeared at the heat exchanger outlet (dew point = +20°F).

The nitrogen outlet temperature at the test heat exchanger outlet was 49.4°F at 0.0°F dew-point heating air and 43.6°F at 20°F dew-point heating air, showing that the cryogenic heat exchanger can meet performance with 20°F dew-point air.

The thawing characteristics are illustrated in Figures 29 through 34, which cover a time of about 16 min.

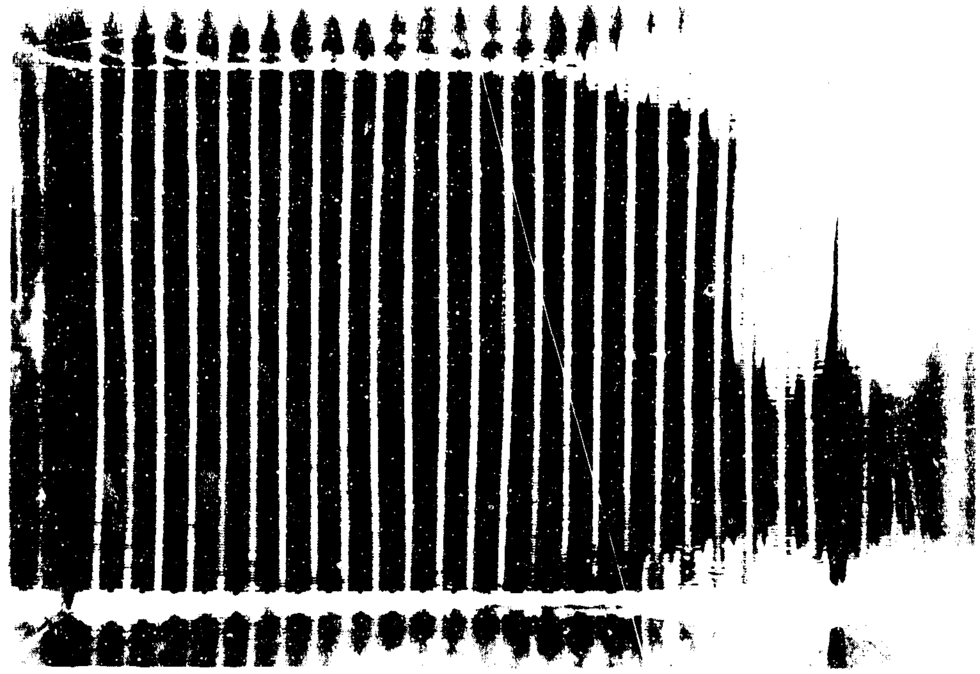


START 0°F DEWPOINT RUN

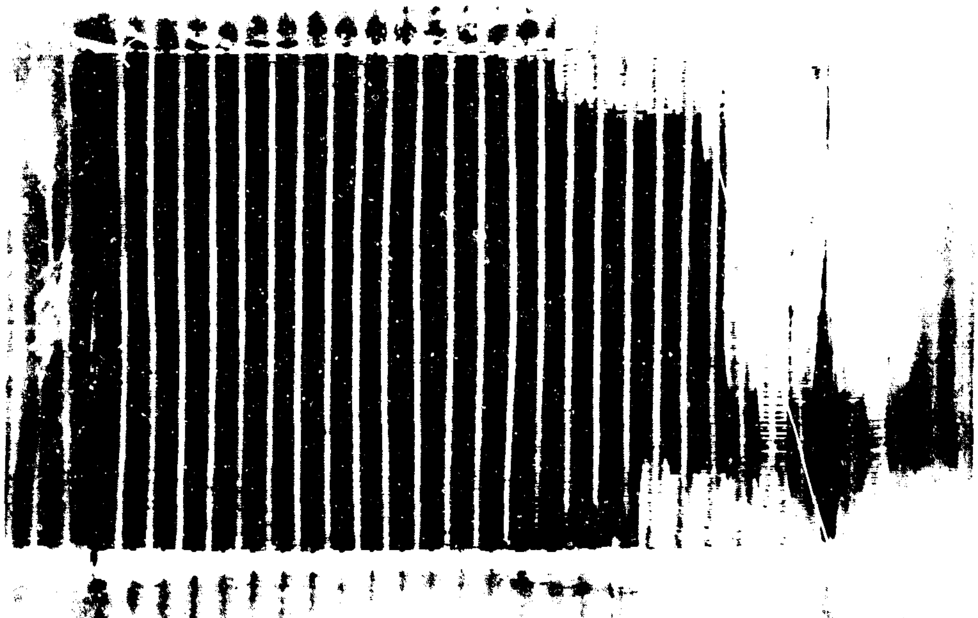


END 0°F DEWPOINT RUN

Figure 24. Dewpoint Test, 0°F Run



START 5°F DEWPOINT RUN



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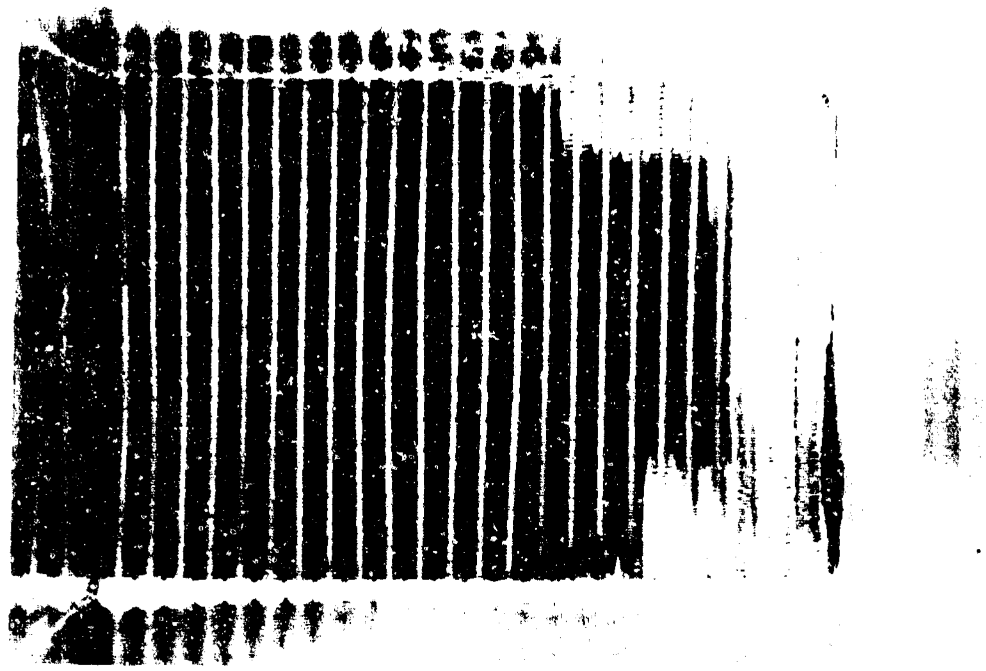
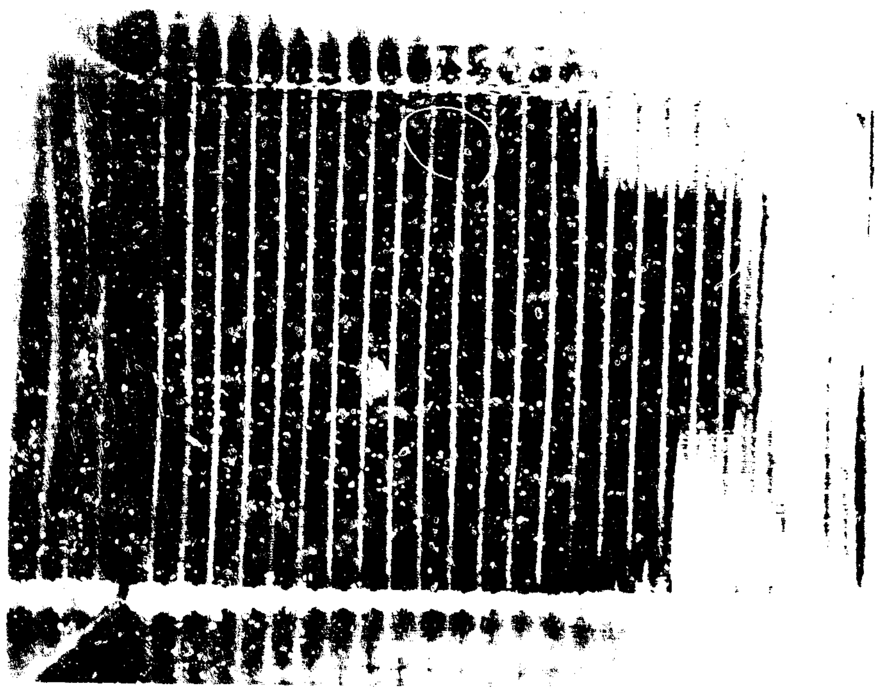
END 5°F DEWPOINT RUN

Figure 25. Dewpoint Test, 5°F Run



START 10°F DEWPOINT RUN



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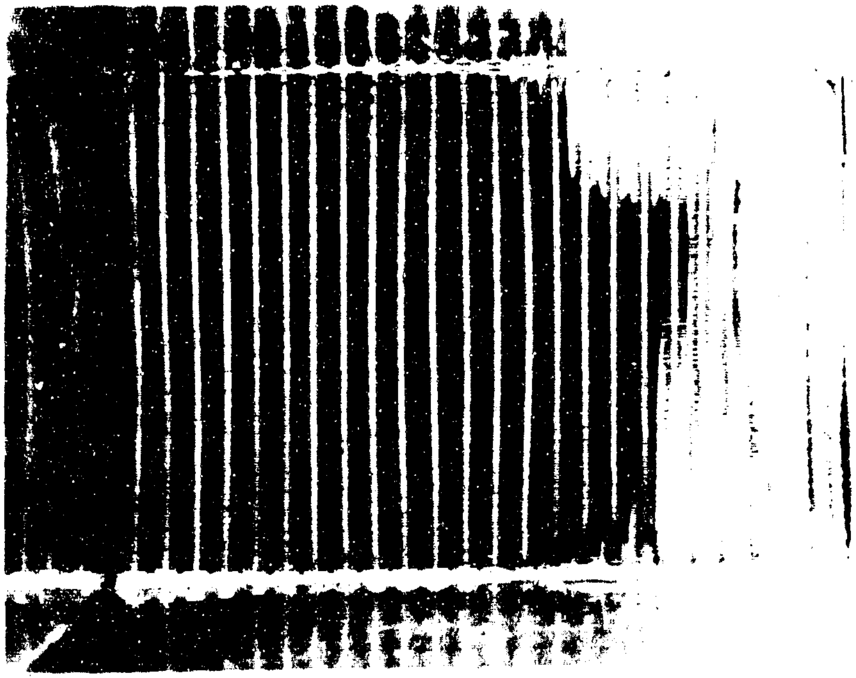
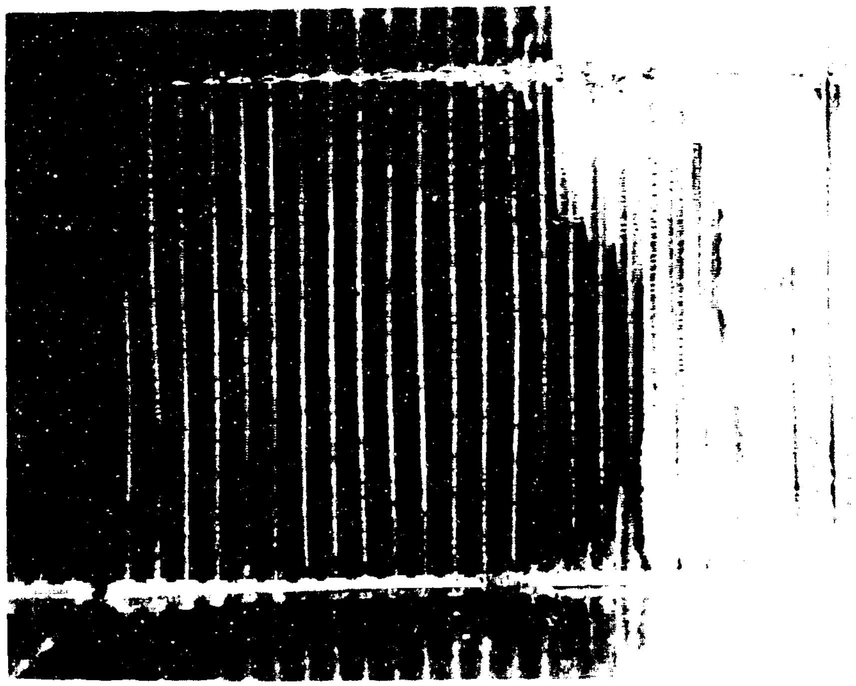
END 10°F DEWPOINT RUN

Figure 26. Dewpoint Test, 10°F Run



START 15°F DEWPOINT RUN



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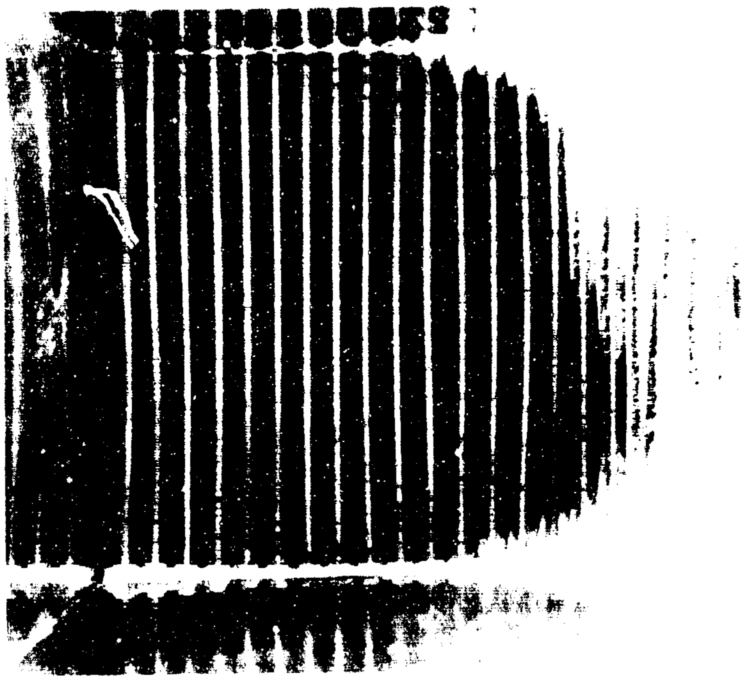
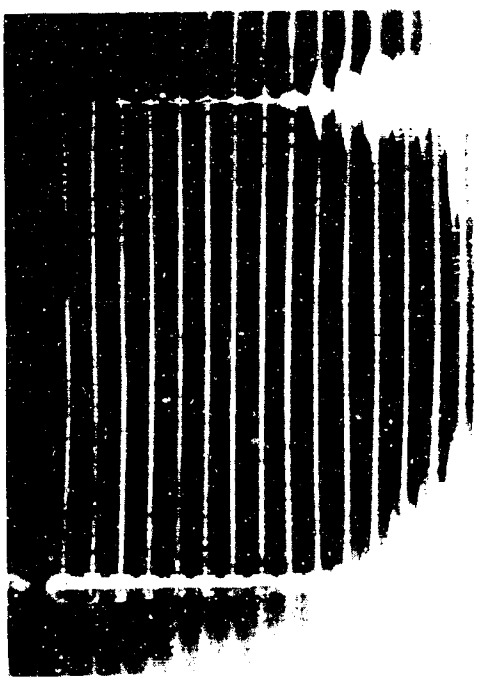
END 15°F DEWPOINT RUN

Figure 27. Dewpoint Test, 15°F Run



START 20°F DEWPOINT RUN



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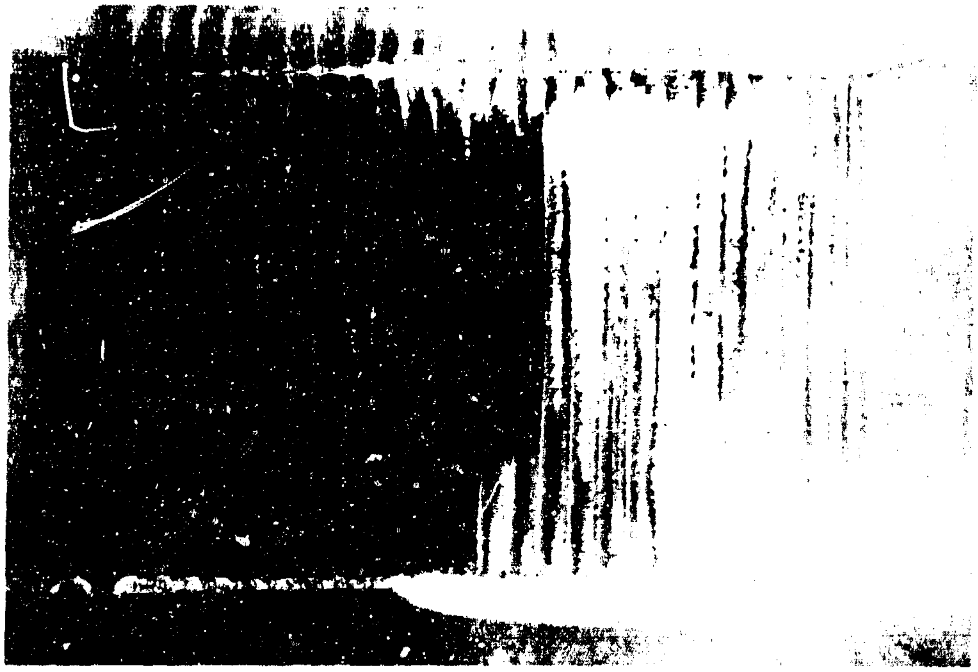
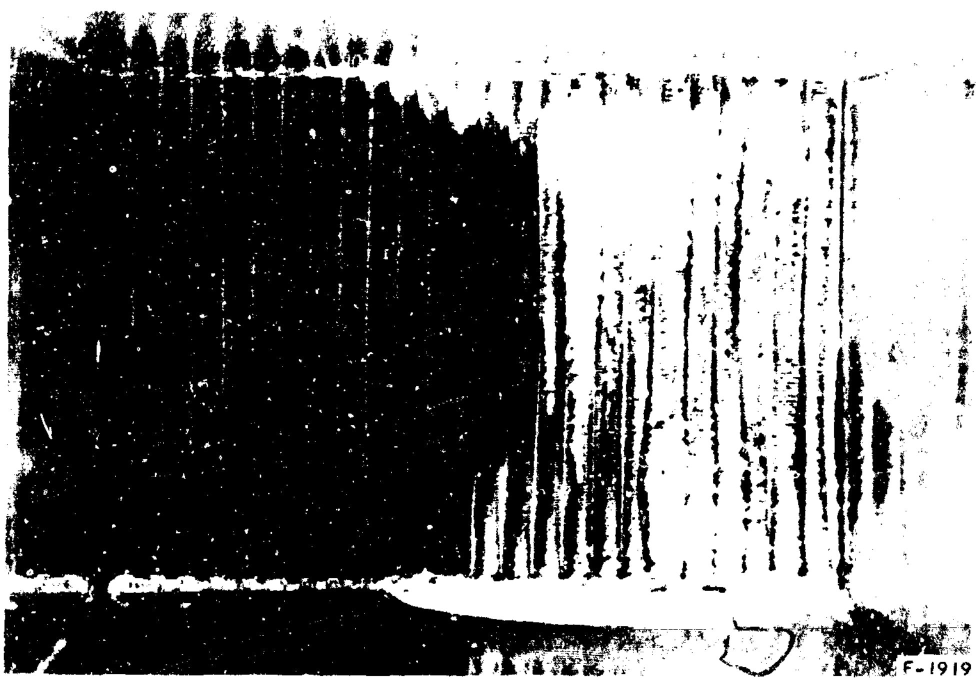
END 20°F DEWPOINT RUN

Figure 28. Dewpoint Test, 20°F Run

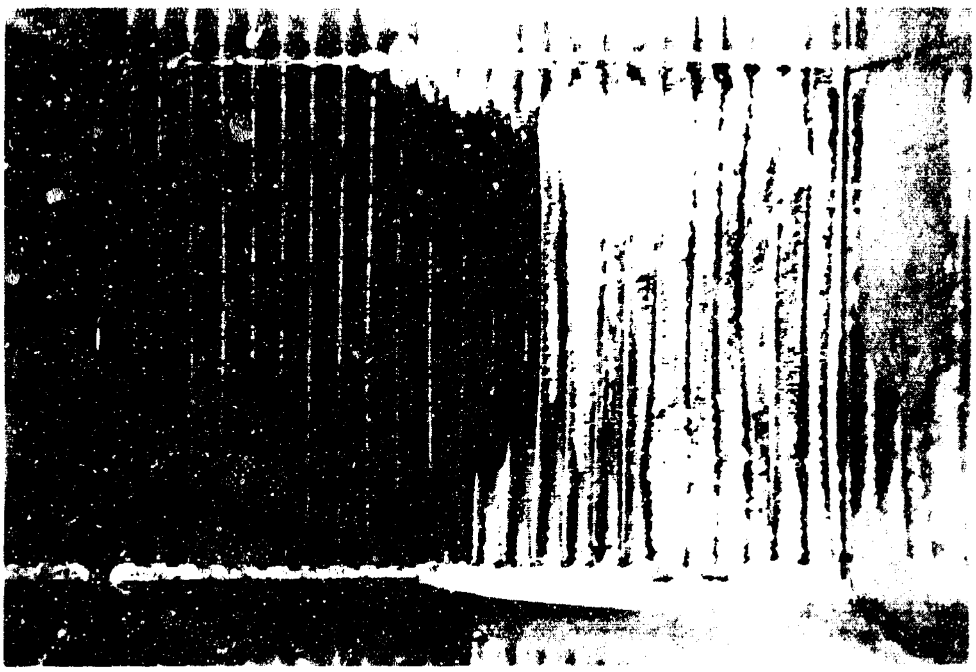


1 MINUTE AFTER N_2 SHUTOFF

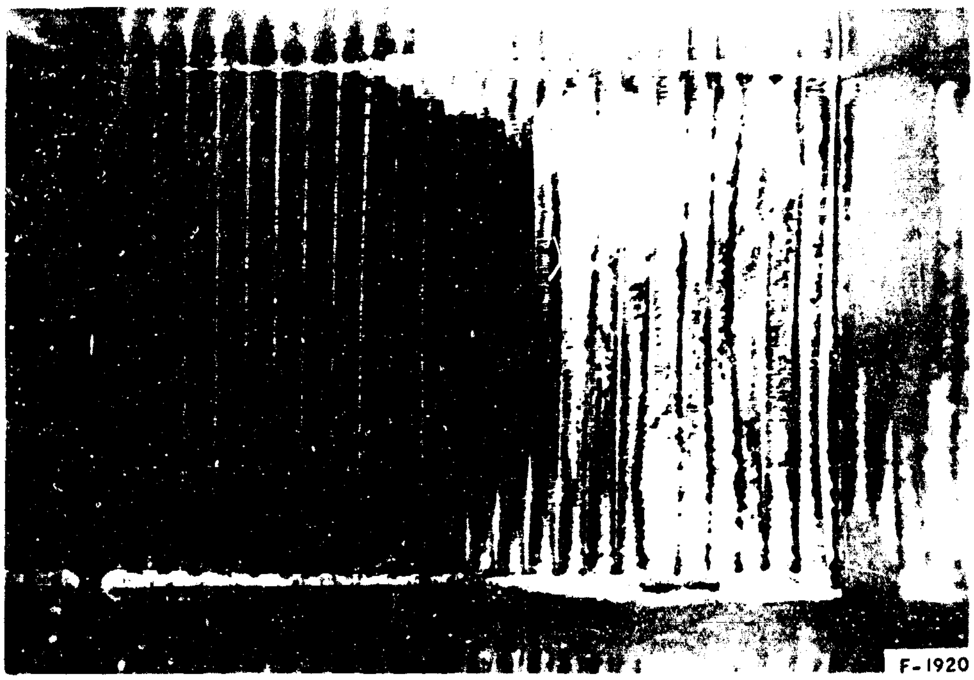


2.25 MINUTES AFTER N_2 SHUTOFF

Figure 29. Thaw Characteristics

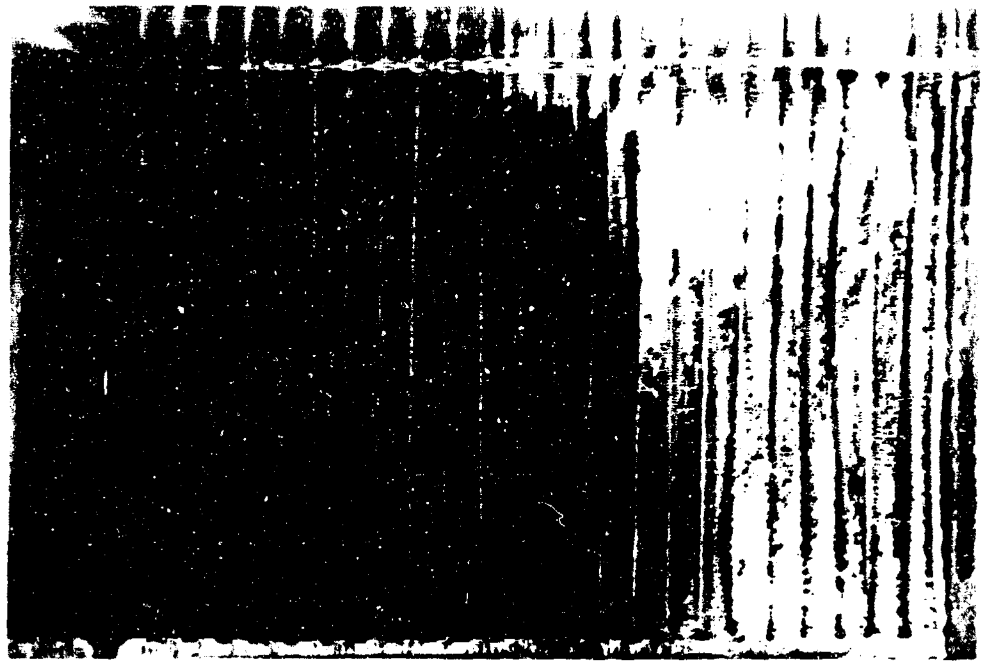


3.5 MINUTES AFTER N_2 SHUTOFF



4.5 MINUTES AFTER N_2 SHUTOFF

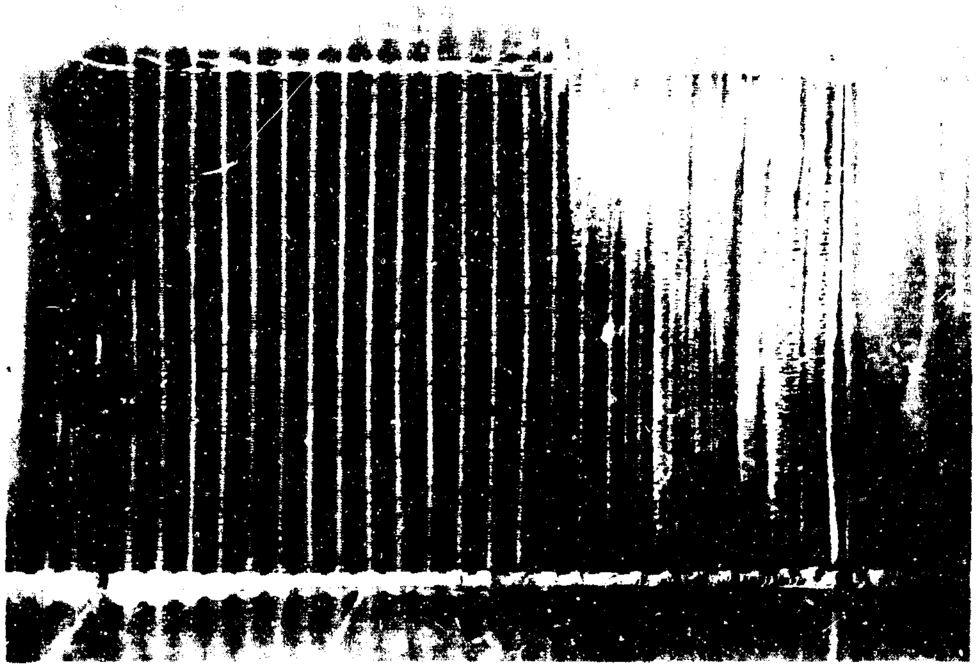
Figure 30. Thaw Characteristics



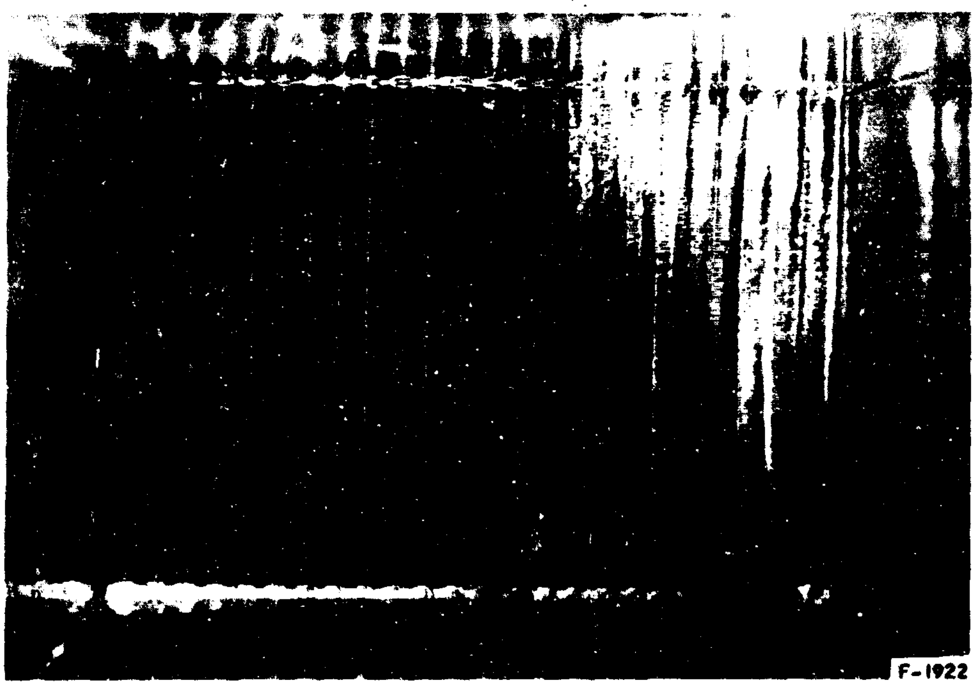
5.5 MINUTES AFTER N_2 SHUTOFF

6.5 MINUTES AFTER N_2 SHUTOFF

Figure 31. Thaw Characteristics

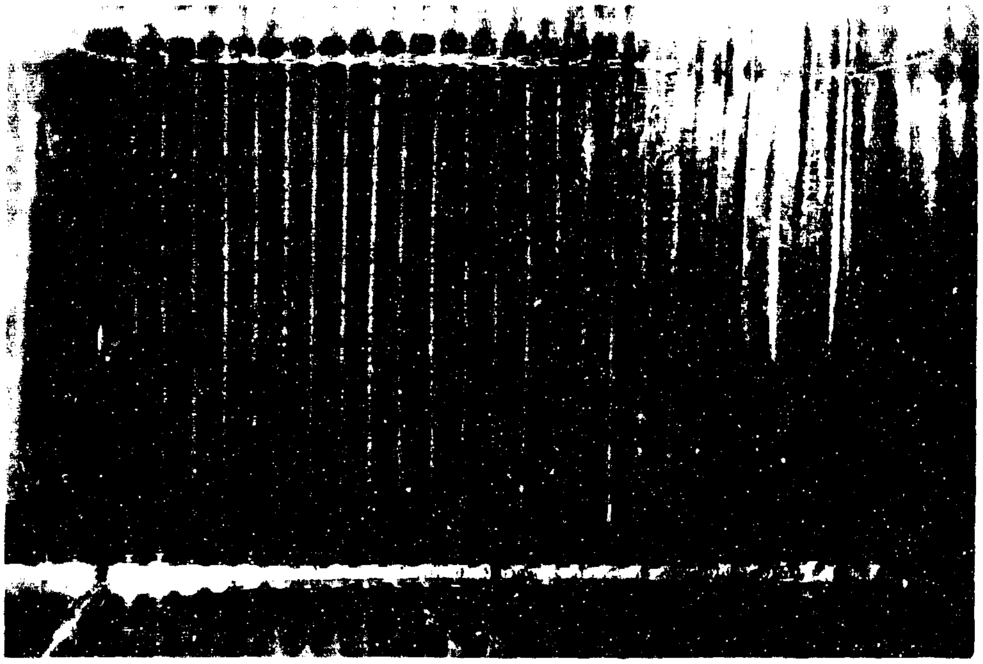


7.5 MINUTES AFTER N_2 SHUTOFF

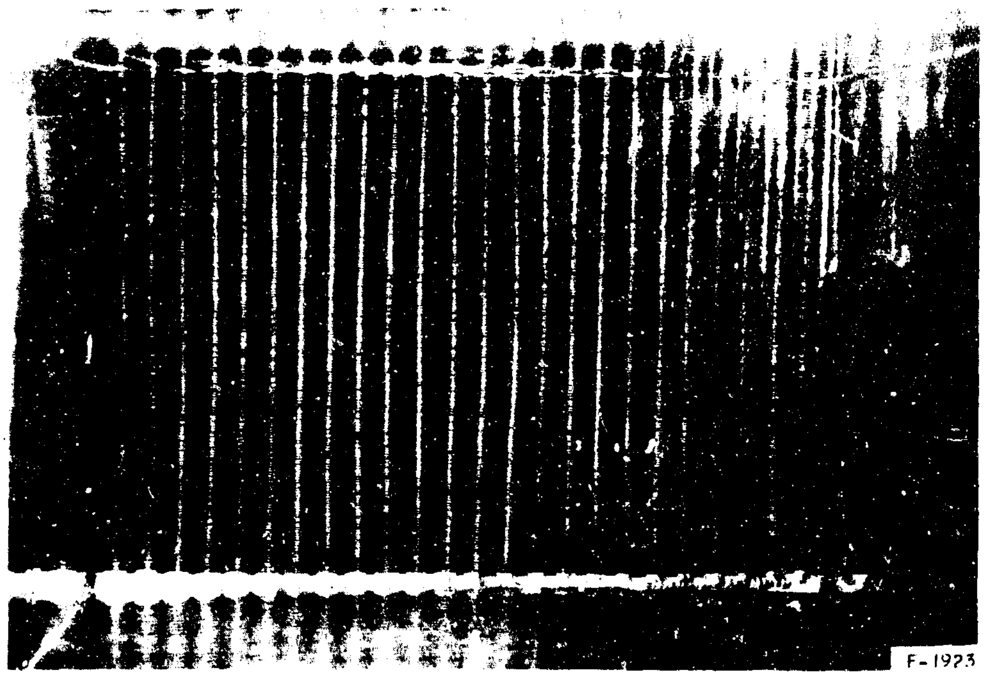


9.5 MINUTES AFTER N_2 SHUTOFF

Figure 32. Thaw Characteristics

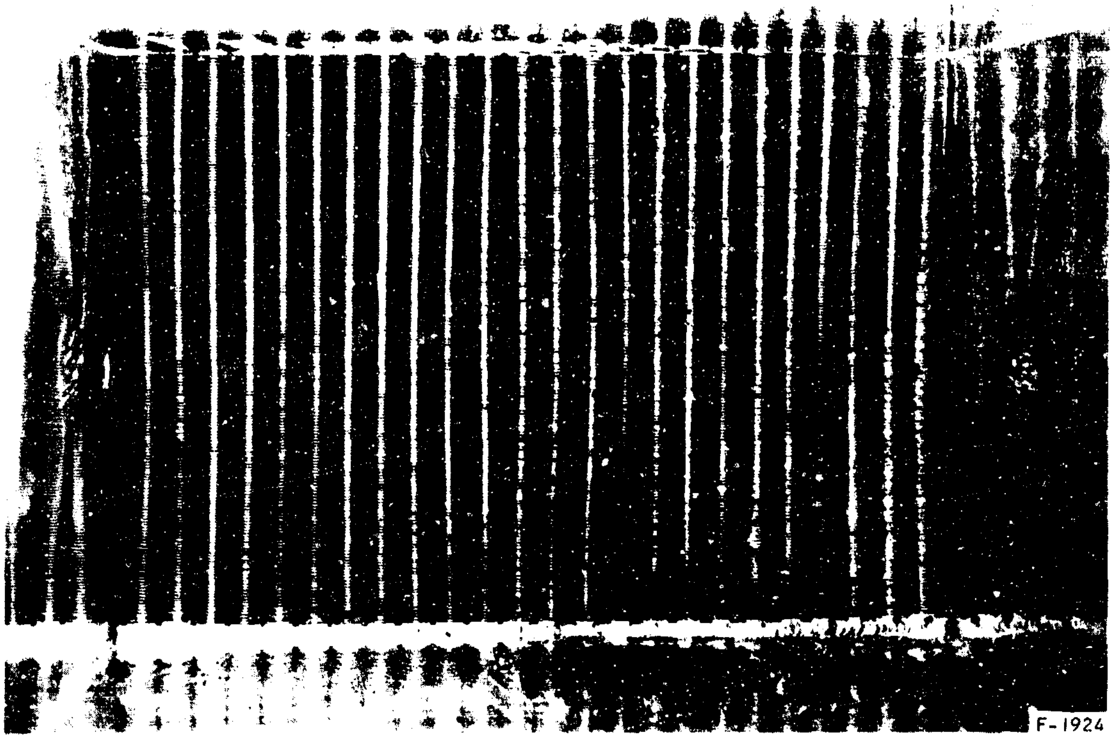


12.5 MINUTES AFTER N_2 SHUTOFF



14.0 MINUTES AFTER N_2 SHUTOFF

Figure 33. Thaw Characteristics



16 MINUTES AFTER N_2 SHUTOFF

Figure 34. Thaw Characteristics

-4 HEAT EXCHANGER, HYDRAULIC FLUID COOLING UNIT 154910-1

Description

The -4 heat exchanger is an aluminum, brazed-and-welded, shell-and-tube heat exchanger which transfers heat from the hydraulic fluid circuit to chilled glycol. The Dyna-Soar thermal management system employs two of these heat exchangers, one in the pilot compartment glycol loop, the other in the equipment glycol loop.

A photograph of the heat exchanger is shown in Figure 35. Figure 36 is a cross-sectional sketch that shows the internal features and illustrates the flow paths.

The fluid port arrangement originally was designed to accommodate a temperature-regulating glycol bypass valve. This accounts for the hydraulic fluid tube through the center of the core, and the glycol return path through a "hat section" outside the heat exchanger shell. The valve was subsequently eliminated, but the fluid connection points had already been frozen. To provide the same connecting points, the present manifold was substituted for the valve.

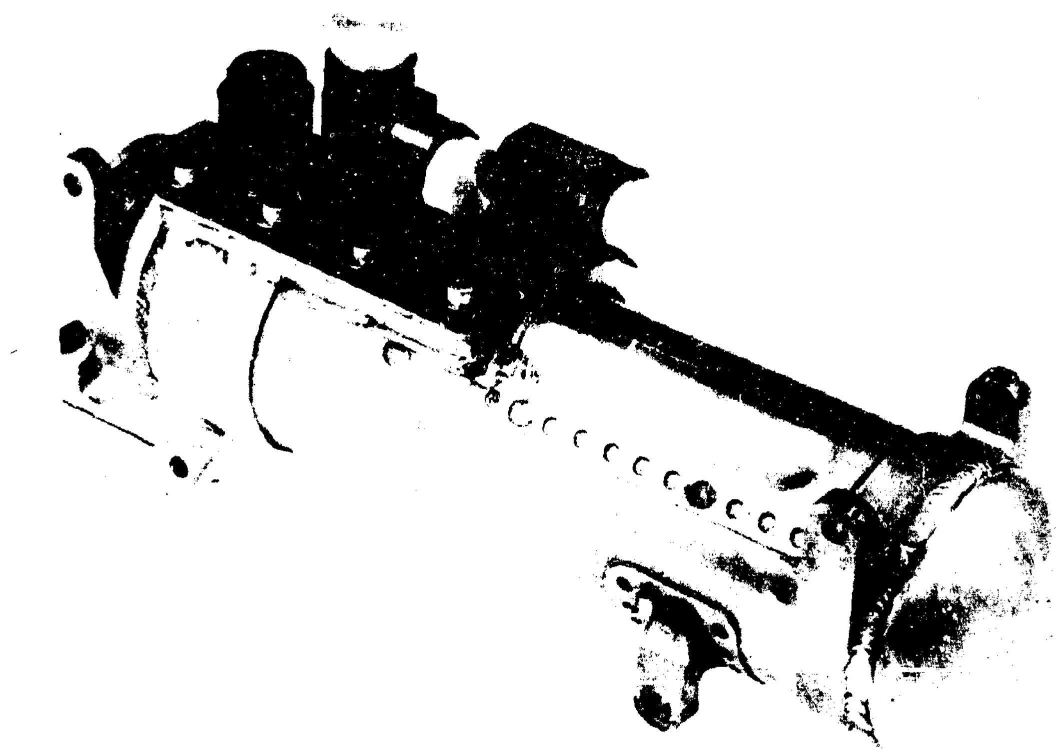
The purpose of the valve was to prevent subcooling of the hydraulic fluid below 100°F during certain low-heat-load, cold-glycol conditions. The hydraulic fluid heat loads and flows were modified, and the minimum allowable temperature was lowered to 65°F, so that the bypass valve was no longer necessary.

Some of the structure, particularly the end cap containing the hydraulic fluid inlet, may appear excessively heavy for this type of heat exchanger. The extra structure in this area was required to support a large cantilever-mounted hydraulic oil filter to be Customer-supplied.

The eight mounting lugs comprise two sets of four lugs each. In this way, it was possible for the identical unit to be mounted in either the pilot or the equipment glycol loop.

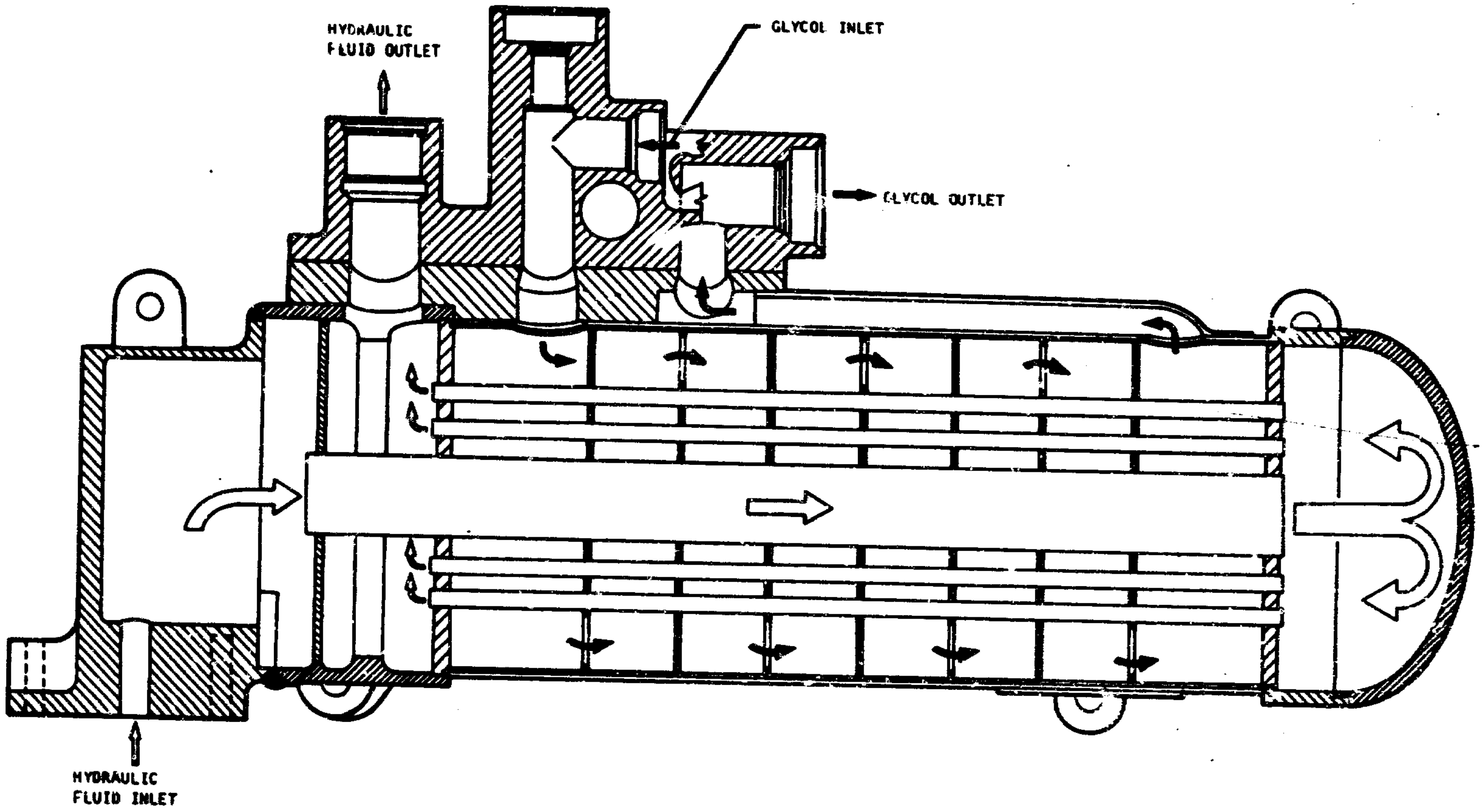
The additional boss above the glycol inlet was at one time to house a glycol-temperature pickup probe. Under the present contract, the boss will simply be fitted with a removable cap as shown in Figure 35.

Because the cross-sectional sketch shows a deceptively small number of tubes, it is pointed out that there are 204 tubes. The tube pattern is such that the view plane cuts only four tubes. For clarity, the other (nonsectioned) tubes are not shown.



49417-2

Figure 35. Hydraulic Fluid Cooling Unit 154910-1



E-1588

Figure 36. Fluid Flow-Paths Hydraulic Fluid Cooling Unit 154910-1

Assembly and Operation

The -4 heat exchanger is a completely welded-and-brazed unit and needs no assembly. The shipping covers and plugs should be removed before the fluid lines are connected. The definition of the fluid ports is shown on the envelope and installation drawing SK 44510, which is furnished separately in a drawing package. The temperature sensor boss should be left capped unless this boss is to be used for instrumentation.

The glycol-water mixture (inhibited ethylene glycol solution), should conform to the composition described under the -1 cooling unit.

The hydraulic fluid should conform to Humble Oil and Refining Company Specification WS-4138 (modified) or Oronite Chemical Company Specification Oronite 7277B. In the East the WS-4138 is obtained from Esso International, Inc. Note that the fluid bosses are special double-seal Mil Flo* fittings and will not receive MS fittings without modification. If it is desired to use MS fittings, the shoulders of each boss should be ground off flush.

If open systems are to be used, it is recommended that a filter having a nominal rating of 20 microns or less be installed in the systems.

Performance

The heat transfer problem statement requires that the unit maintain the hydraulic fluid outlet temperature between 100°F and 250°F under normal conditions, and between 65°F and 250°F under failed-compartment conditions, when the glycol flow is 4.5 to 5.4 lb per min and the heat loads and hydraulic fluid flows are as follows:

Condition	Heat Load (Btu per min)	Hydraulic Fluid Flow (gpm)
1	156	0.79
2	67	0.76
3	254	0.98
4	378	1.52
5	365	2.05
6	387	2.13
7	127	0.74 (failed compartment condition)
8	318	0.74
9	61	0.30

*Mil Flo Corporation, Dayton, Ohio

The failed-compartment condition means that no heat is added to the glycol by the compartment upstream of the -4 heat exchanger (as in the case of compartment fan failure) so that the glycol inlet temperature is a minimum, about 47°F.

The most significant conditions in the listing above are the one most likely to produce a hydraulic fluid temperature above 250°F, Condition 5, and the one most likely to produce an oil temperature below 65°F, Condition 7. Condition 5 is considered to be the design point. The respective fluid temperatures for these two conditions, along with the maximum heat transfer condition, are summarized in the problem statement below:

	Units	Design Point	Maximum Heat Load	Low Oil Temperature Condition
Hydraulic Fluid Side				
Heat load	Btu per min	365	387	127
Flow	gpm	2.05	2.13	0.74
Inlet temperature	°F	298	299	116
Outlet temperature	°F	250	250	65
Pressure drop (Isothermal)				
at 2 gpm, 20°F	psi	49		
at 8.5 gpm, 100°F	psi	27		
Glycol Side				
Flow	lb per min	5.4	5.4	5.4
Inlet temperature	°F	166	161	47
Outlet temperature	°F	250	250	79.5

The -4 heat exchanger meets or exceeds all the performance requirements. This is discussed further in the performance test description.

1. Heat Transfer Test

a. Test Setup--The cooling unit was connected to temperature-controlled sources of hydraulic fluid and glycol, with the lines instrumented to measure flow, temperature, and pressure drop. The fluid lines between the thermocouples and the test unit were insulated to minimize heat loss.

b. Procedure--The hydraulic fluid and glycol flows were stabilized at each of the tabulated conditions. The fluid flows and temperatures were recorded after stabilization at each condition.

Hydraulic Fluid Side			Glycol Side	
Flow (lb per min)	Inlet Temp (°F)	Outlet Temp (°F)	Flow (lb per min)	Inlet Temp (°F)
High Temperature Conditions				
2.6	305	resulting	1.0, 2.0, 4.0, 8.0, 16.0	152
4.0	305	resulting	1.0, 2.0, 4.0, 8.0, 16.0	152
8.0	305	resulting	1.0, 2.0, 4.0, 8.0, 16.0	152
16.1	305	resulting	1.0, 2.0, 4.0, 8.0, 16.0	152
32.6	305	resulting	1.0, 2.0, 4.0, 8.0, 16.0	152
Low Temperature Conditions				
4.6, 9.5, 18	resulting	65	54	40

c. Results--The heat transfer test results for the high temperature condition are presented in Figure 37 in terms of overall thermal conductance (UA) as a function of glycol flow for a family of hydraulic fluid flows. At the design-point glycol flow of 4.5 lb per min and hydraulic fluid flow of 15.0 lb per min, the available UA was (by interpolation) 8.5 Btu per min-°F, or greater.

The UA obtained for the low temperature runs is shown in Figure 38. The UA was appreciably lower than for the high temperature runs, as would be expected. The calculated UA that would result in a hydraulic fluid outlet temperature of 65°F at this condition is plotted on the graph for comparison with the test results. This calculated UA nearly coincides with the test results, showing that the hydraulic fluid will not be cooled below 65°F at the low-heat-load, failed-compartment cooling unit condition.

d. Discussion--The hydraulic fluid cooling unit originally was designed with five baffles instead of seven on the glycol side. At that time, the specified maximum hydraulic fluid outlet temperature was 240°F. This required a UA of 7.5 Btu per min-°F, at the design condition. Tests on the first unit yielded an available UA of 7.0 Btu per min-°F. To improve the heat transfer performance, the number of baffles was increased from five to seven without enlarging the unit. This change increased the UA from 7.0 to 8.5 as Figure 37 shows. Although a single additional baffle would have been ample, two were used so that the glycol flow path terminated on the same side of the shell (reference Figure 36).

After the design had been changed, the problem statement was relaxed to permit hydraulic fluid outlet temperatures up to 250°F. The new problem required a UA of only 5.8 Btu per min-°F at the design point.

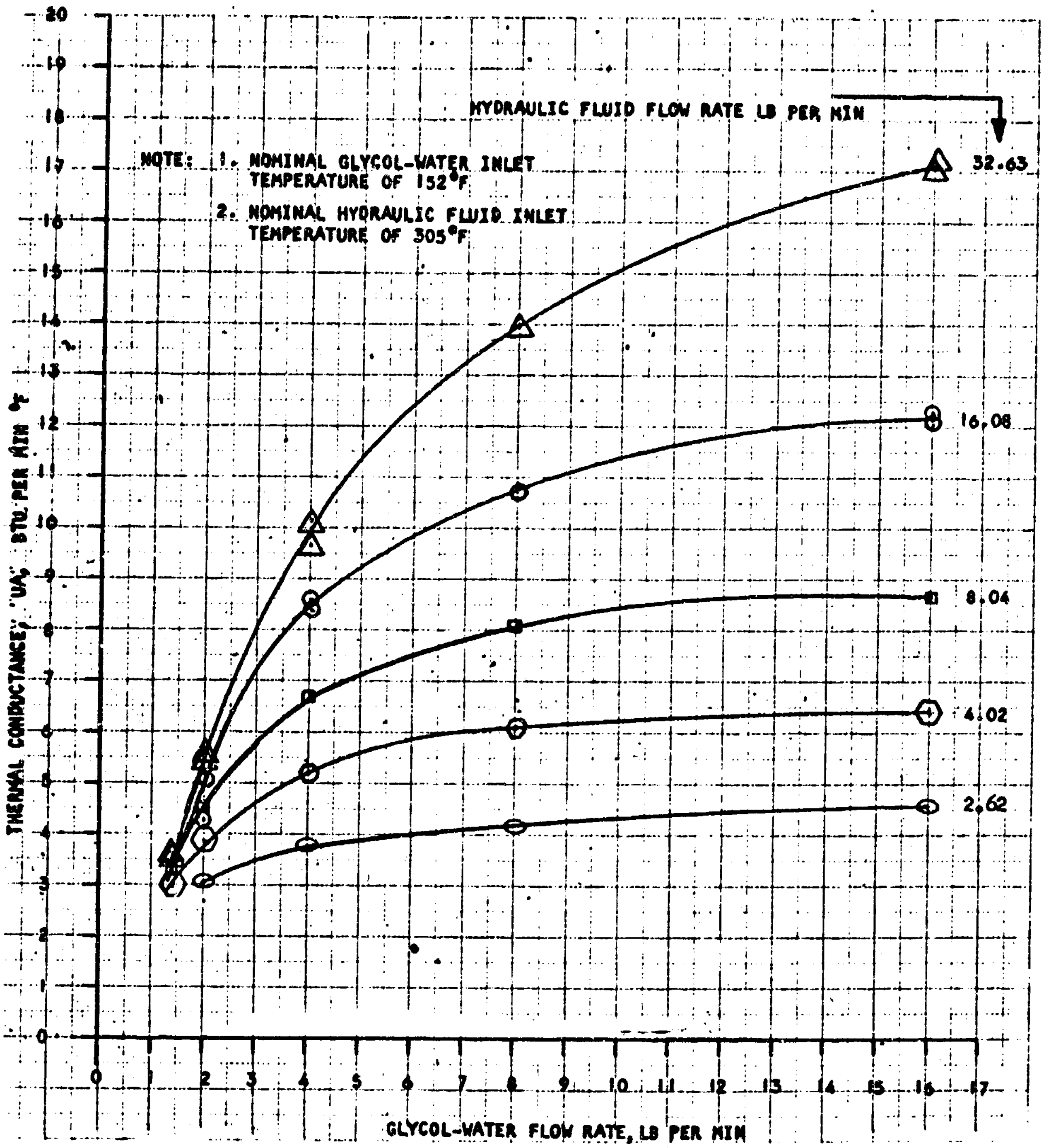


Figure 37. Heat Transfer Performance

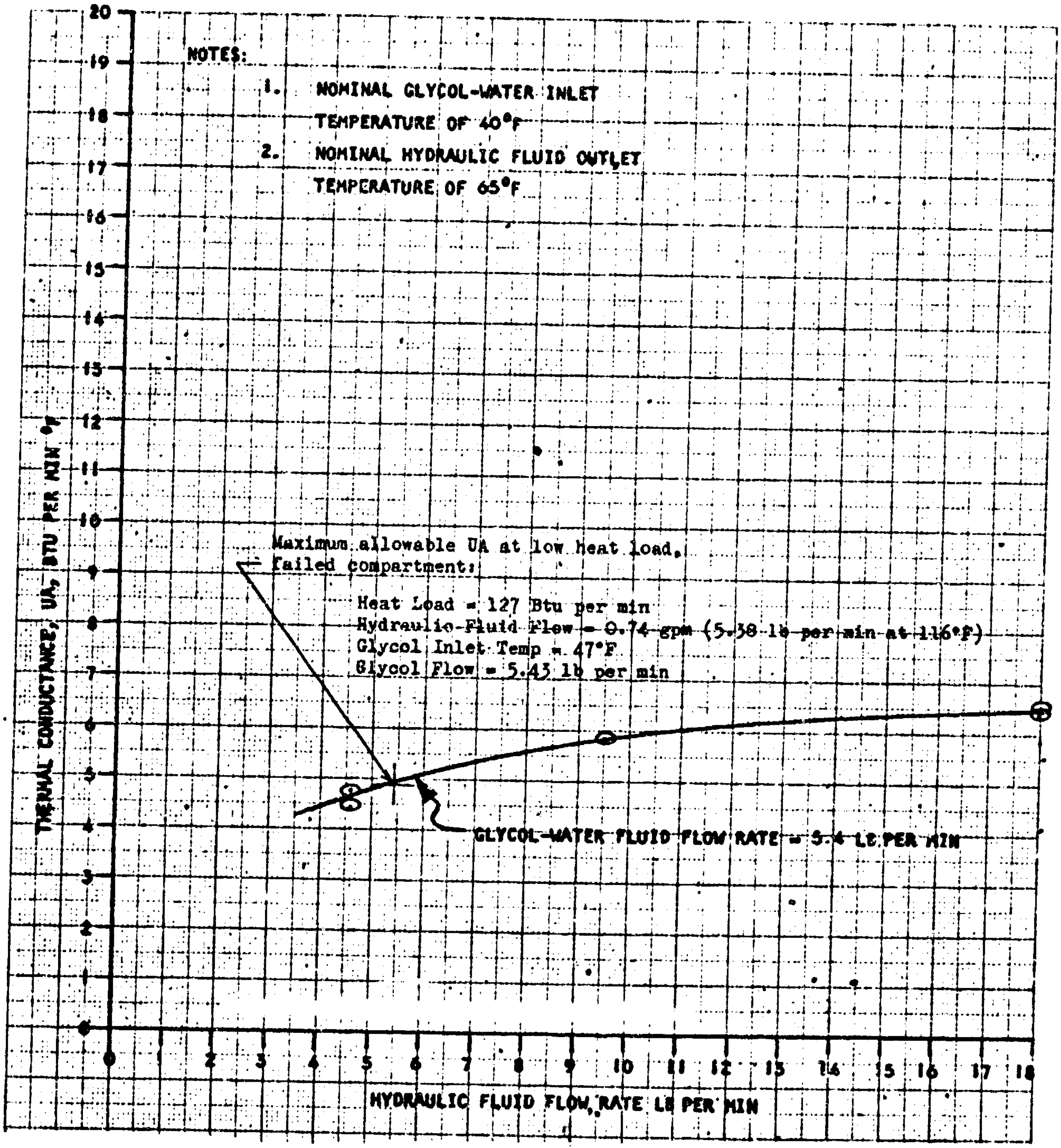


Figure 38. Low Temperature Performance

Although the cooling unit had more performance margin with respect to the new problem statement than is normally considered necessary, it was felt desirable to retain the seven-baffle design, provided the hydraulic fluid outlet temperature did not fall below 65°F during the low-heat-load, failed-compartment cooling unit condition (called the "low temperature condition" for convenience). This 47°F temperature is based on glycol leaving the glycol temperature control at 10°F and acquiring a minimum of 138 Btu in the cold plate, APU, and pump unit (0 Btu from the failed-compartment cooling unit) for a temperature increase of 37°F (reference Figure 1 under System Description).

This temperature increase is based on a glycol flow of 5.43 lb per min, which is the nominal glycol pump flow setting at a glycol temperature of 100°F. With the colder glycol, the flow will be somewhat less than nominal, resulting in a greater temperature increase upstream of the hydraulic fluid cooling unit, as well as reduced UA in the cooling unit. These effects combine to keep the hydraulic fluid outlet temperature above 65°F.

2. Pressure Drop Test

a. Test Setup--The setup for the pressure-drop test was the same as for the heat transfer test, except that there was no fluid flow through the glycol passages. The glycol passages were open to ambient.

b. Procedure--The hydraulic-fluid pressure drop was measured for a range of flows from 1.1 to 8.5 gpm at fluid temperatures of 45, 60, and 100°F.

c. Results--The pressure drop test results are presented in Figure 39, which shows static pressure drop as a function of hydraulic fluid flow for various hydraulic fluid temperatures. The pressure drop at 8.5 gpm and 100°F was 25 psi, and the pressure drop at 2.0 gpm and 45°F was 42 psi. The allowable pressure drops at these temperatures and flows are 27 and 49 psi, respectively.

3. Hydraulic Fluid Transient

The hydraulic fluid transient tests were conducted in two parts: (1) a temperature cycling test in which the inlet temperature and flow of the hydraulic fluid were varied abruptly from a stabilized base condition that corresponded to maximum heat load, and (2) a test in which a number of spikes were applied in accordance with a specified flow-time schedule while the fluid inlet temperature was held constant.

a. Procedure: Part I Tests--Operation of the hydraulic fluid cooling unit was established initially at the steady-state conditions tabulated in the next paragraph. After stabilization for at least 60 sec, the hydraulic fluid flow and the inlet temperature at the cooling unit were abruptly increased to 8.5 gpm and 400°F for 5 sec, and were then returned to the initial steady state condition. The conditions were cycled in this manner for 10 hr, which resulted in 555 such hydraulic fluid transients, with steady state conditions established for 60 sec between each transient spike.

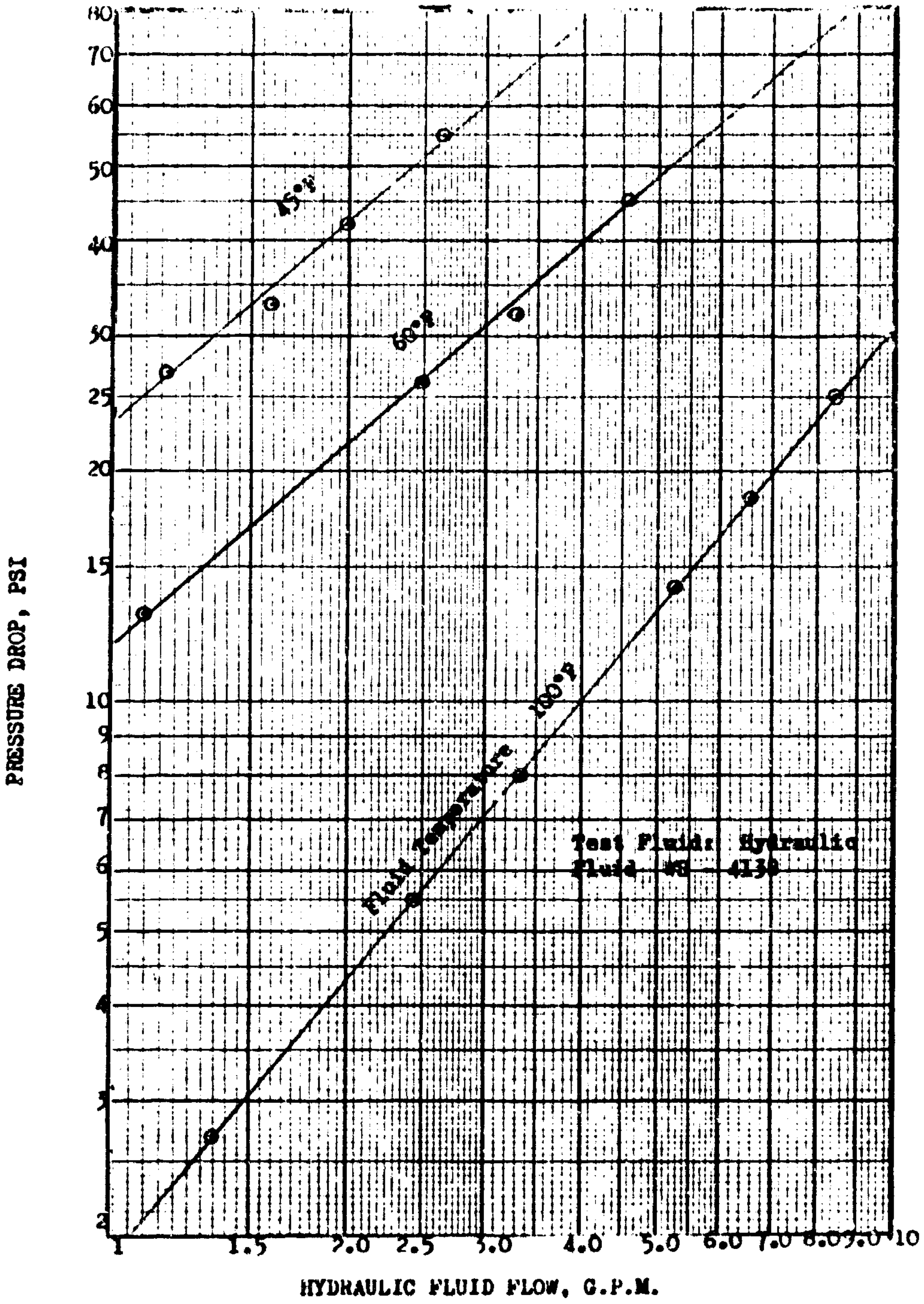


Figure 39. Pressure Drop Performance

The steady state conditions were:

Hydraulic fluid inlet temperature	287 ±5°F
Hydraulic fluid flow	2.18 ±0.12 gpm
Heat load (reference)	361 Btu
Glycol inlet temperature	163 ±5°F
Glycol flow	5.5 ±0.25 lb per min

Two consecutive cycles were recorded by oscillograph after each fiftieth cycle throughout the 10-hr duration of the test. Data were also recorded manually every 30 min.

b. Results: Part 1 Tests--The hydraulic fluid outlet temperature reached a maximum of 349°F 5 sec after the start of the spike condition. The glycol outlet temperature reached a maximum of 325°F 22 sec after the spike.

c. Procedure: Part 2 Tests--The hydraulic fluid inlet temperature for this test was held constant while a number of flow-rate spikes (transients) were applied with the unit operating initially at steady-state condition A and again at steady-state condition B in accordance with the following schedule. The steady flow condition was reestablished after each spike.

	Steady-State Condition A	Steady-State Condition B
Hydraulic fluid inlet temperature	383 ±5°F	337 ±5°F
Hydraulic fluid flow rate	0.7 ±0.04 gpm	1.17 ±0.04 gpm
Glycol inlet temperature	163 ±5°F	164 ±5°F
Glycol flow rate	5.45 ±0.3 lb per min	5.45 ±0.3 lb per min

Spike Condition

Hydraulic Fluid Flow (gpm)	Duration (sec)
9	2
6	4
5	10
4	28
3	75
2	190

d. Results: Part 2 Tests--The maximum hydraulic fluid and glycol outlet temperature occurred during the application of the 4-gpm, 28-sec-duration hydraulic fluid spike applied in conjunction with the 0.7-gpm flow at 383°F. The maximum outlet temperatures were 334°F (hydraulic fluid) and 353°F (glycol), and were attained at 23 and 27 sec, respectively. The high-flow condition was attained within 0.1 sec. Upon the return to steady-state flow conditions, the hydraulic fluid outlet temperature dropped to 284°F at 33 sec from the flow spike.

The glycol outlet temperature increased from 276°F to 300°F in 8 sec, and remained above 300°F (maximum 353°F) for 45 sec.

No detrimental effects were observed on the unit as a result of conducting this test.

THE -7 PUMP PACKAGE, GLYCOL DUAL PUMP UNIT 178410-1

Description

The pump package, shown in Figure 40, consists of two identical pump and accumulator assemblies mounted side-by-side by means of two brackets. The package circulates chilled aqueous ethylene glycol heat-transport fluid through the Dyna-Soar pilot-compartment cooling loop and the equipment loop, with one pump for each loop. Each pump and accumulator assembly consists of an electric-motor-driven, gear-type pump, an integral spring-loaded accumulator, and a linear potentiometer position indicator as shown in the cross-sectional sketch included in Figure 40.

The electric motor is shown in Figure 41 with the rotor and quill shaft removed. The nondriving end of the pump housing is completely closed and, when joined to the remainder of the pump and accumulator assembly, completes the sealed enclosure as shown in Figure 40. The housing contains the stator, which is completely encapsulated in epoxy and sealed with silicone rubber for operation while submerged in pressurized glycol solution.

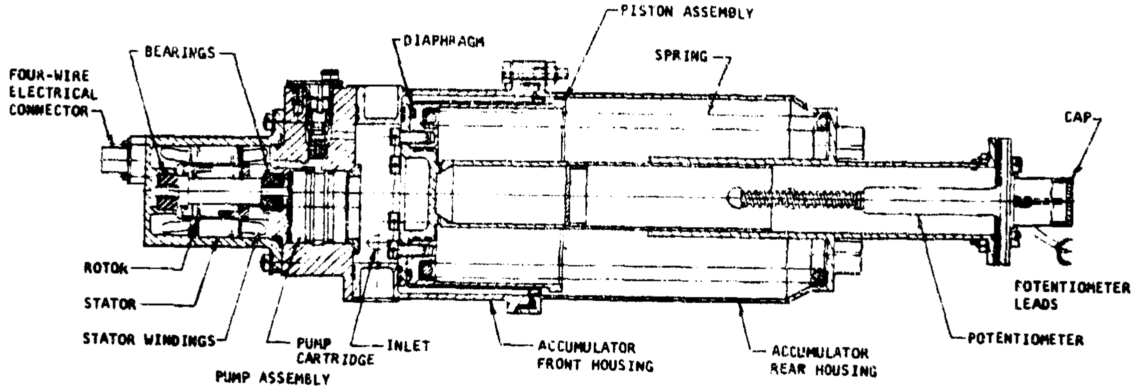
The motor drives the pump cartridge through the free-floating, quill shaft shown in Figure 41. To obtain maximum length for the quill shaft so that potential misalignment effects are minimized, the shaft extends through the entire length of the hollow rotor shaft and engages an internal spline at the far end.

The rotor itself is supported by two graphitic carbon brushings, one in the motor housing and the other in the pump housing. Bearing area and clearance are optimized for minimum drag consistent with performance and life requirements.

The pump housing contains the gear pump cartridge (manufactured by Adel Division, General Metals Corporation), the outlet port, the flow calibration bypass, and the pressure relief bypass valve. An exploded view of the pump housing is shown in Figure 42. The pump flow calibration bypass valve is the exploded assembly to the right, with the three-hole mounting pattern. The bypass is required because the pump capacity is greater than the required flow. This adjustment is set by AiResearch before delivery.

Figure 42 also shows the pump cartridge removed from the housing; the view shows the inlet side. The retainer which holds the pump cartridge is the inlet glycol screen. The pump housing also contains the pressure relief bypass valve. It is installed in the threaded hole in the housing above and to the right of the pump cartridge cavity as viewed in the photograph.

An exploded view of the pump cartridge itself is shown in Figure 43. The gears are made of a case-hardened, nitride steel alloy known as Nitralloy. This material provides the necessary wear resistance to withstand the 11,000-rpm speed for 2000 hr of operation. The bushings are graphitic carbon.



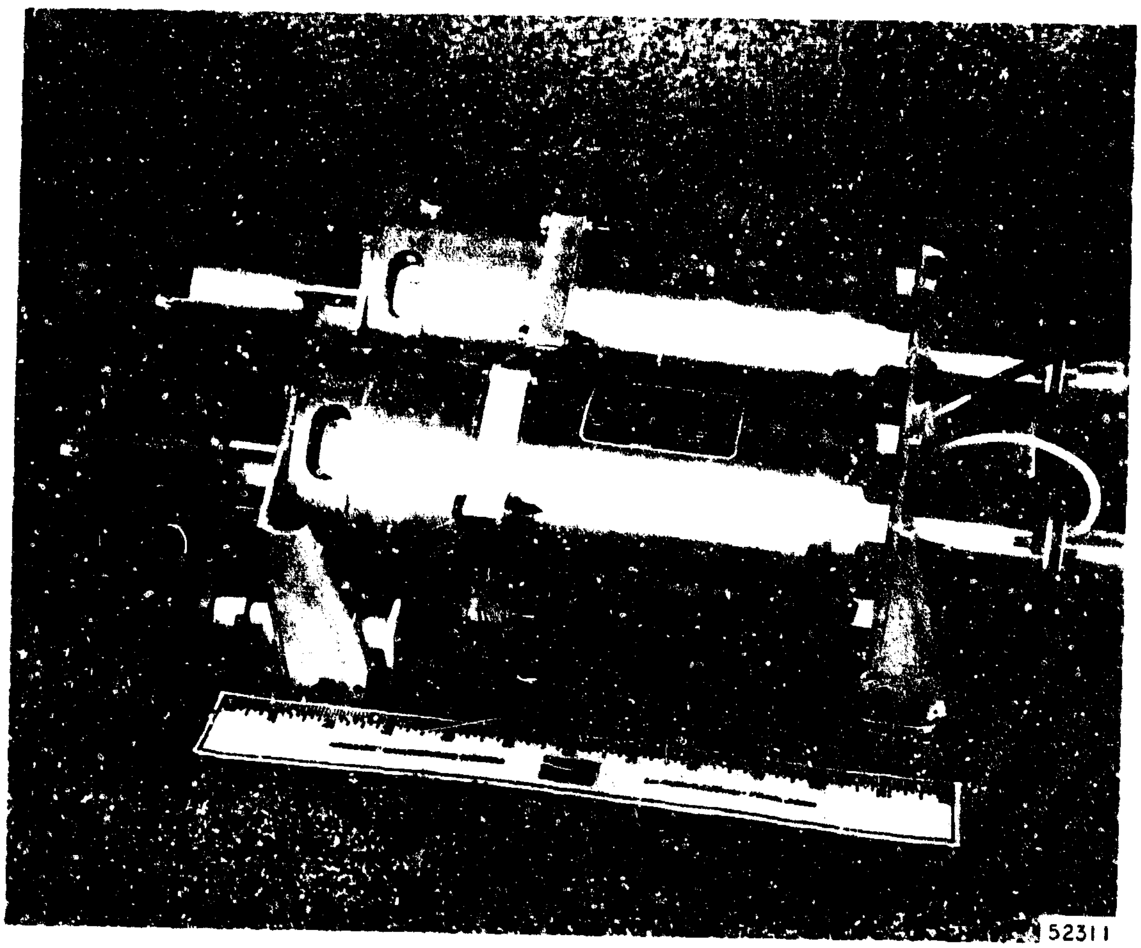


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Figure 40. Glycol Dual Pump Unit

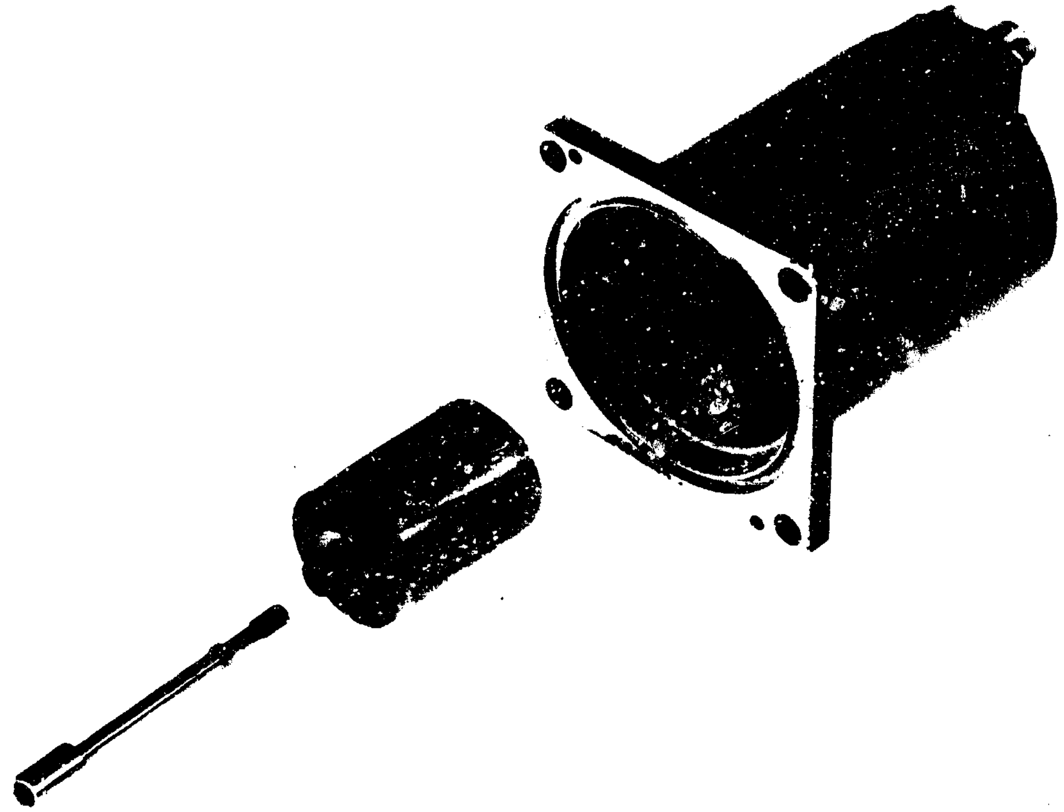

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Figure 41. Pump Motor

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Figure 42. Exploded View of Pump Housing

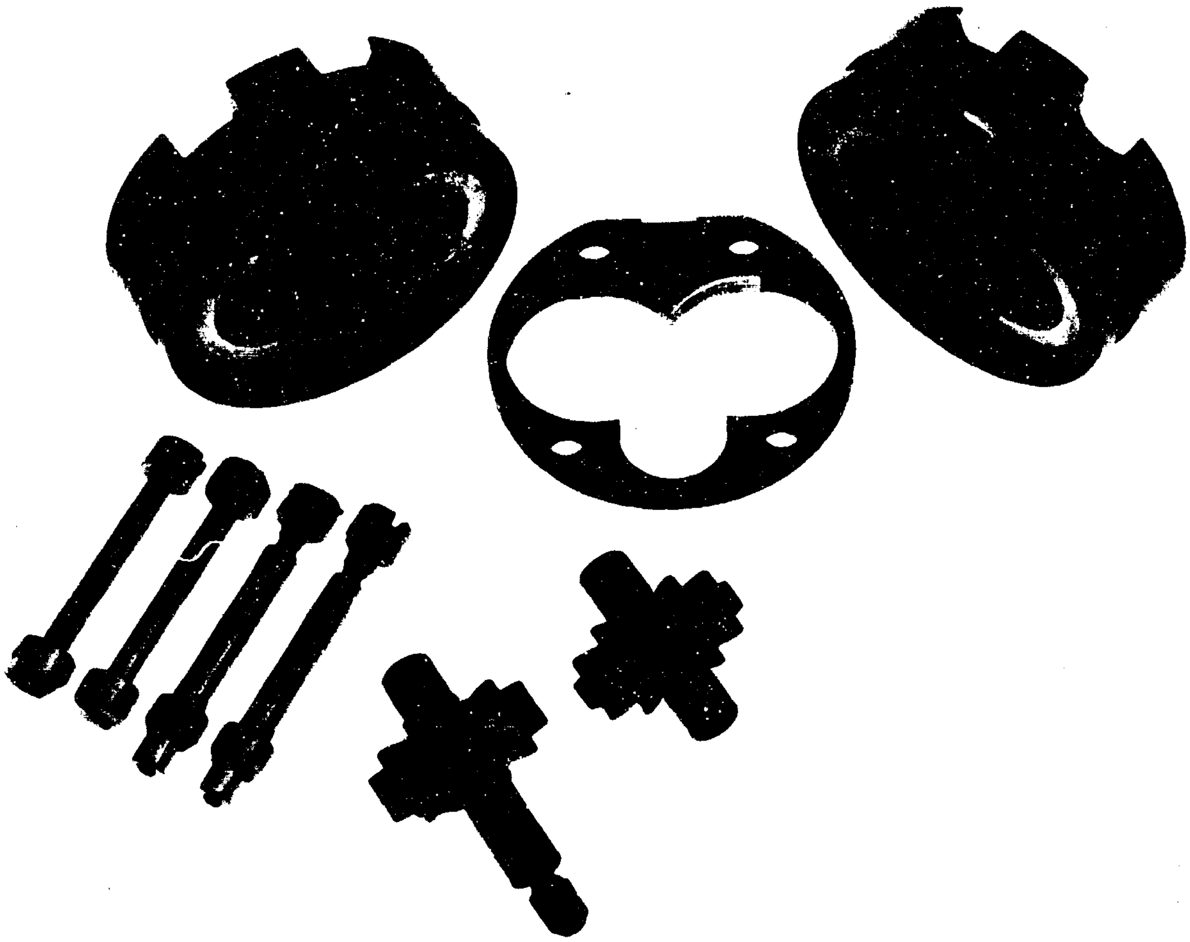

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Figure 43. Pump Cartridge

The inlet side of the pump housing bolts directly to the accumulator, which is shown exploded in Figure 44. The accumulator housing is made in two sections for ease of assembly: a front housing and a rear housing. The front housing contains the inlet port and the pump inlet plenum.

An unusual feature of this accumulator is the seal on the piston face. When the accumulator reservoir is empty, the piston bottoms on a sealing shoulder on the front housing (position shown in cross section, Figure 40). This prevents a reverse differential from being applied to the diaphragm, which might back-roll or wrinkle the diaphragm if the glycol system were to be evacuated preparatory to filling. The seal also affords a safety margin by preventing total loss of system glycol should the diaphragm leak. Because the piston bottoms before the accumulator is absolutely empty, the seal traps a small, residual volume of fluid between the piston skirt and accumulator wall when the accumulator is nominally empty.

The potentiometer position indicator (shown in the schematic, Figure 40, but not shown in the photograph, Figure 44) is mounted on the end of the accumulator so that it is engaged by the piston during the last 25 percent (the last inch of approximately 4 inches) of travel in the filling direction. The potentiometer is a three-wire, sliding-tap, linear proportional voltage divider, which provides an accurate indication of the piston position during the last 25 percent of the filling operation. It was intended for use only during ground service (filling) and to verify the proper reservoir level after transition from ground-furnished glycol cooling to self-contained Dyna-Soar system cooling. Note, also, that an indicating rod extends out from the potentiometer for a quick visual reference of the fill status.

Assembly and Operation

The operating fluid is an aqueous ethylene glycol solution prepared as described under the discussion of the -I unit. The inlet and outlet ports are defined by Envelope Drawing SK44511, submitted separately. Note that the bosses are designed to receive special Mil Flo* fittings and will not receive MS fittings without modification. For MS fittings, the shoulder should be ground off flush.

The pump requires 115/200 v, three-phase, four-wire, 400-cps electric power. The electrical connectors are defined in SK44511. Each pump has its own connector. The circuit schematic for each pump is shown on a decal on each dual-pump unit.

The potentiometer is designed for operation on 28 v dc, but, being a simple variable resistor, will provide proportional voltage division for lower input voltages. In test work, AiResearch frequently uses a 6-v battery for this purpose. The leads from both potentiometers terminate in a single electrical connector (defined on Drawing SK44511) but have separate terminals as shown in the schematic of the unit.

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*Mil Flo Corporation, Dayton, Ohio

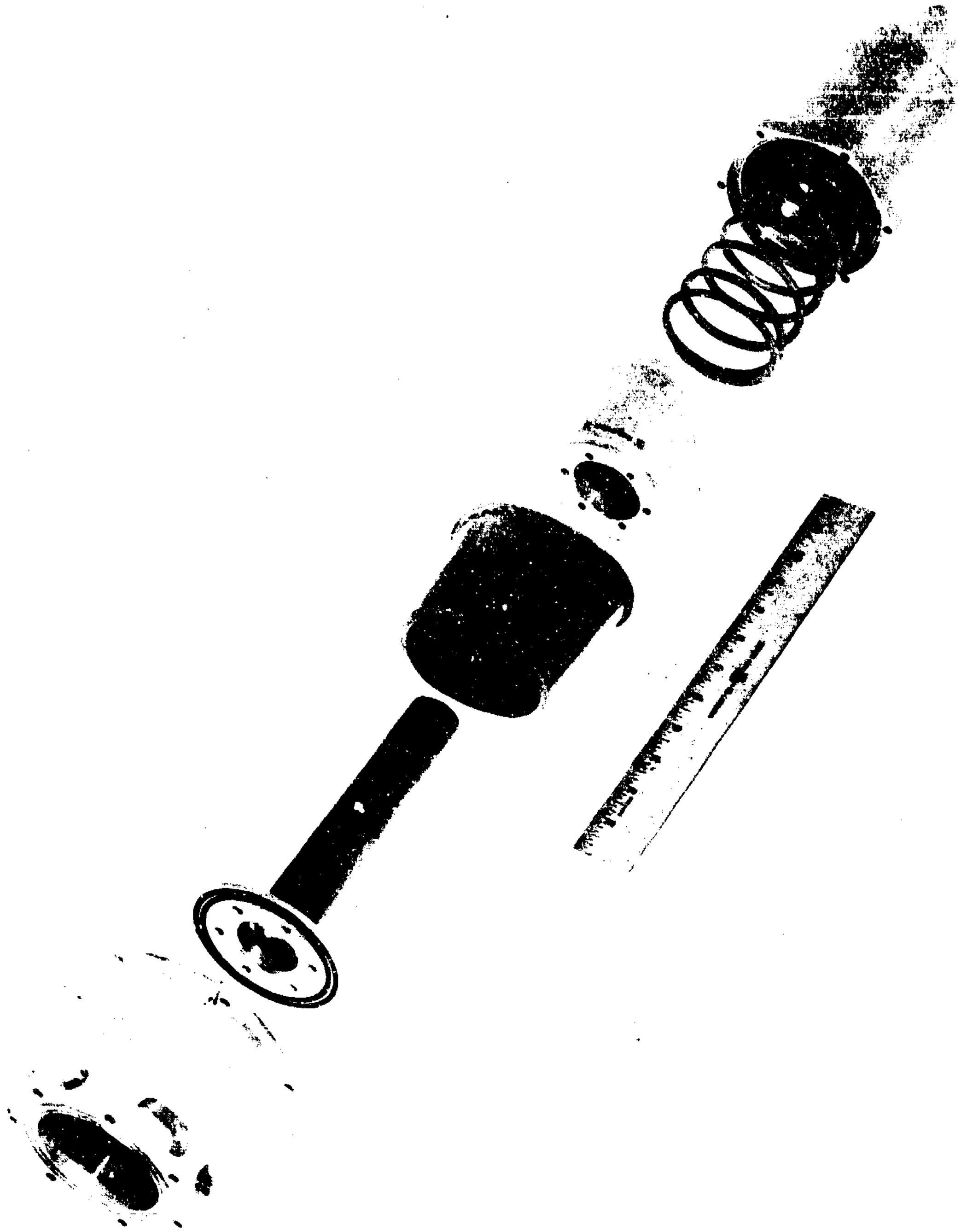

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Figure 44. Accumulator Assembly

For test purposes, a ratiometer, an ohmmeter, or in the case of a known constant-voltage source, a voltmeter, provide satisfactory indication of the reservoir fluid volume. The relationship between piston travel, potentiometer resistance, and pressure is shown in Figure 45. The relationship between piston travel, pressure, and fluid volume is shown in Figure 46.

The pump package may be operated with glycol inlet pressures from 6 to 16 psig, but a recommended operating level for test purposes is 10 to 14 psig to ensure an adequate supply of fluid in the accumulator and to allow space for fluid expansion.

The accumulator should not be filled, nor should the pump be wet with glycol, until filling the system. The glycol clinging to the pump surfaces might form a sticky, crystalline substance. In time, the deterioration of the fluid can lock the gears and prevent starting of the pump.

Performance

Each pump of the dual pump package is designed to provide the glycol flows at the conditions tabulated.

	Normal Flow Setting	Maximum Flow Setting: Design Point	Maximum Flow Setting: Failed Compartment (Low Temperature)
Glycol flow, lb per min	5.43 ± 0.3	6.1 ± 0.3	5.5 ± 0.3
Pressure rise, psi	60 ± 5	100	110
Fluid temperature, ^{o}F	100 ± 5	90 ± 40	-5
Electrical power, max, watts	140	140	225
Pump inlet pressure, psig	13 ± 1	6-16	6-16
Bypass setting	As Req'd.	Closed	Closed

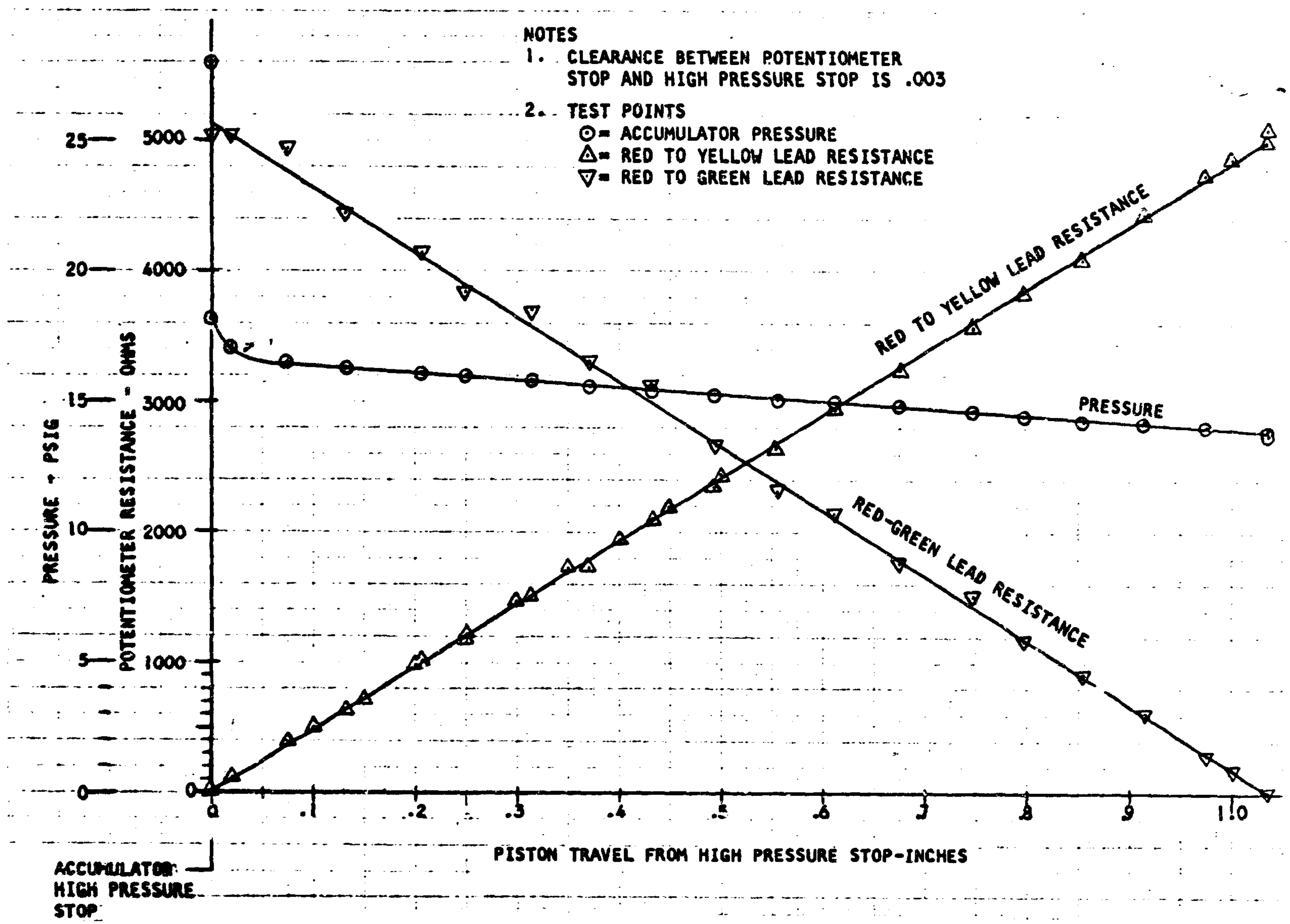

Figure 45. Potentiometer Calibration

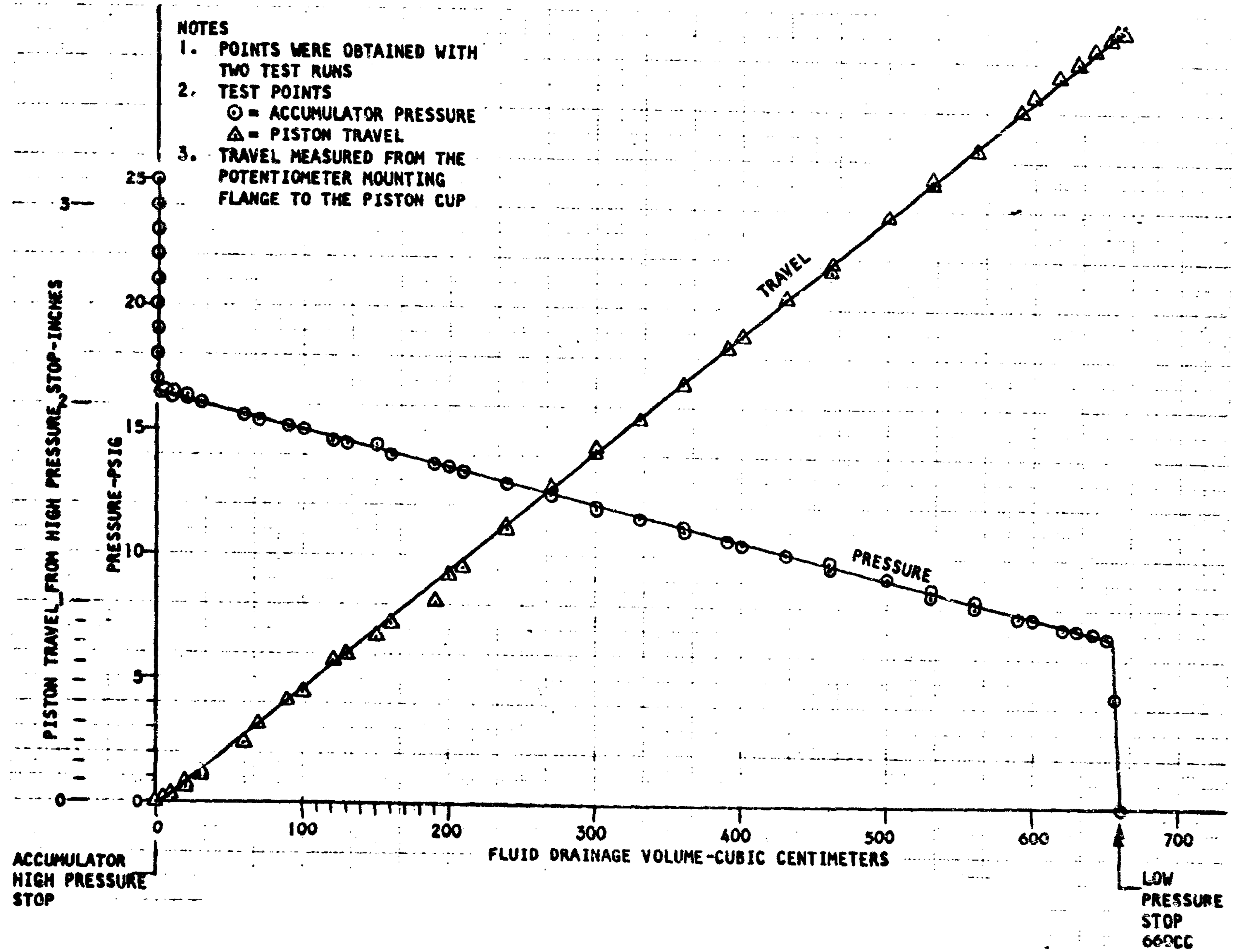

Figure 46. Accumulator Displacement Calibration

The "normal" flow condition is established arbitrarily on the basis of anticipated pump inlet temperature and pilot-loop pressure drop at the maximum pilot-compartment heat load. The normal flow is obtained by adjustment of the internal bypass. The maximum flow setting was a specified design condition, but not representative of actual conditions to be encountered in the Dyna-Soar. The pumps are calibrated to the normal flow setting before shipment. Pump power and flow for other than normal pressure rise can be approximated from Figure 49, presented later in the performance test section.

Other significant features of the pump package are:

Reservoir volume (each accumulator): 40 cu in.

Power type: Motor - ac, 115/200-v, 3-phase, 4-wire, 400-cps

Potentiometer - 28-v d-c

Potentiometer resistance: 4960 to 5000 ohms (between yellow and green leads)

Pressure relief, discharge blocked: 125 ± 10 psi

Minimum recommended inlet pressure: 6 psia

Weight: Dry - 15.47 lb

Wet - 19.47 lb

Life: 2000 hr

1. Motor Performance Test

a. Procedure for Dry Motor--The following performance data were taken and recorded at speed increments within the range of no-load to locked rotor conditions.

Motor torque

Motor speed

Phase currents

Phase voltages

Power input

b. Procedure for Viscous Drag Losses--With the motor assembly removed from the dynamometer and repositioned vertically (motor rotor axis vertical, with output end of shaft up), the motor case was filled with a glycol-water mixture having a composition by weight of 65 percent glycol and 35 percent water, plus additives. The motor was then run at no-load conditions with the

quill shaft removed. The vertical orientation of the motor assembly was necessary to avoid the use of fluid seals at the output end of the motor assembly and thus eliminate those frictional forces associated with such seals. The viscous drag losses (converted to watts) thus obtained were applied to data obtained for dry performance data tests and used as a basis for an estimated performance curve for a glycol-water-filled motor assembly.

c. Results--Figure 47 shows the performance plot for the dry motor, with the principal motor variables plotted as a function of torque. The stall data and the pull-out torque are indicated in notes on the figure.

Figure 48 also shows the estimated performance of the submerged motor, based on the data for the dry motor with the calculated effects of viscous drag applied.

2. Motor Reactance Test

a. Procedure--The reactance test for the motor assembly (fitted with ball bearings) was run using a dry motor case. Normal operation is with a motor case filled with a glycol-water solution. The testing sequence was as follows:

Negative Sequence Reactance

(1) The motor was connected for normal operation. The rotor was driven in the opposite direction by the dynamometer at a synchronous speed.

(2) The voltage applied to the motor was adjusted, in each phase, to obtain rated phase current.

Zero-Sequence Reactance

(1) The three-phase electrical leads from the motor were connected together (short-circuited) and the rotor driven at synchronous speed by the dynamometer.

(2) A small, single-phase voltage was then applied to the "shorted" phase leads and the neutral lead of the motor.

(3) The voltage was adjusted to obtain rated phase current.

Subtransient Reactance

(1) The motor assembly was connected for normal operation. A high-speed oscillograph was used to record all voltages and currents.

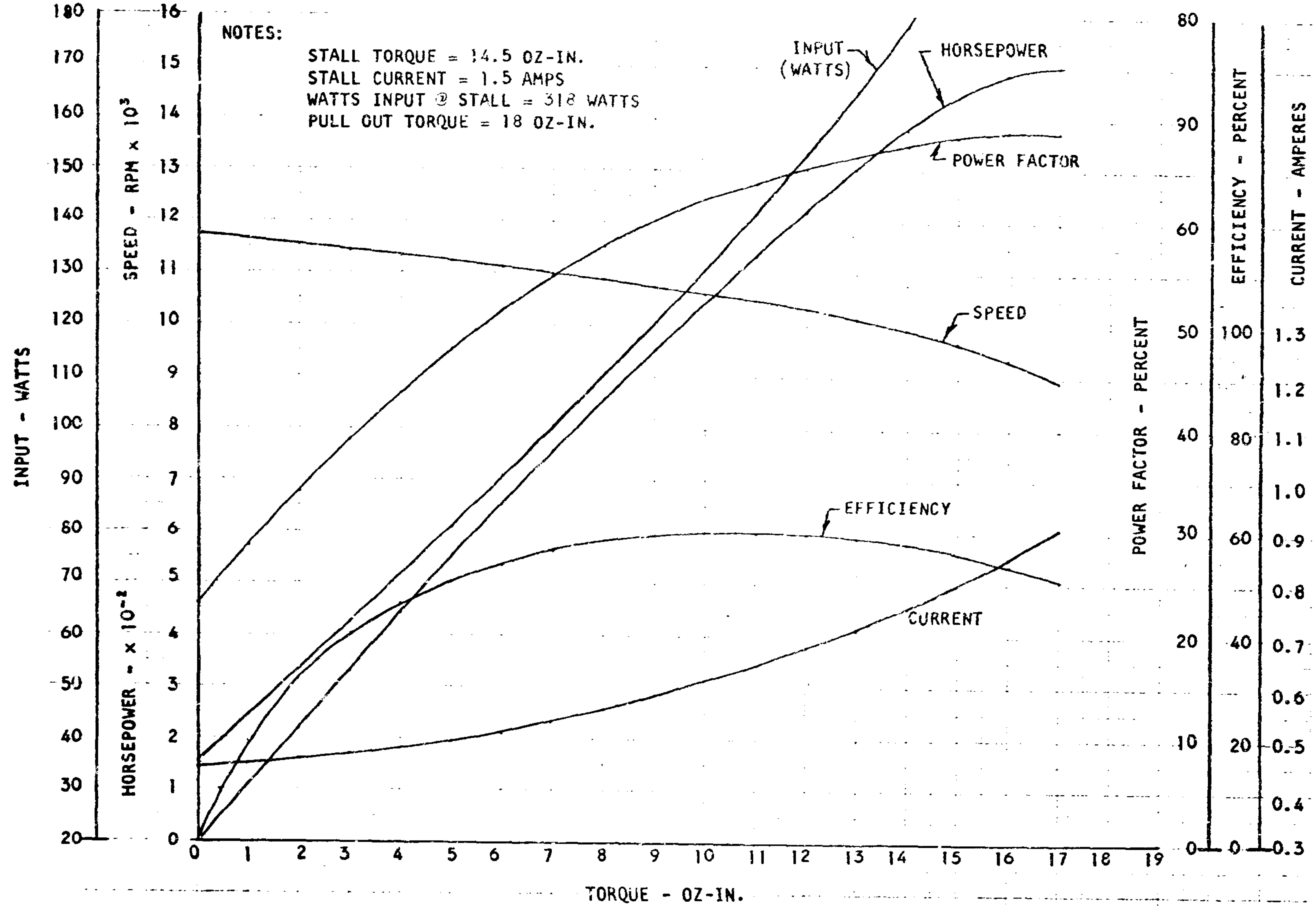

Figure 47. Motor Performance, Dry

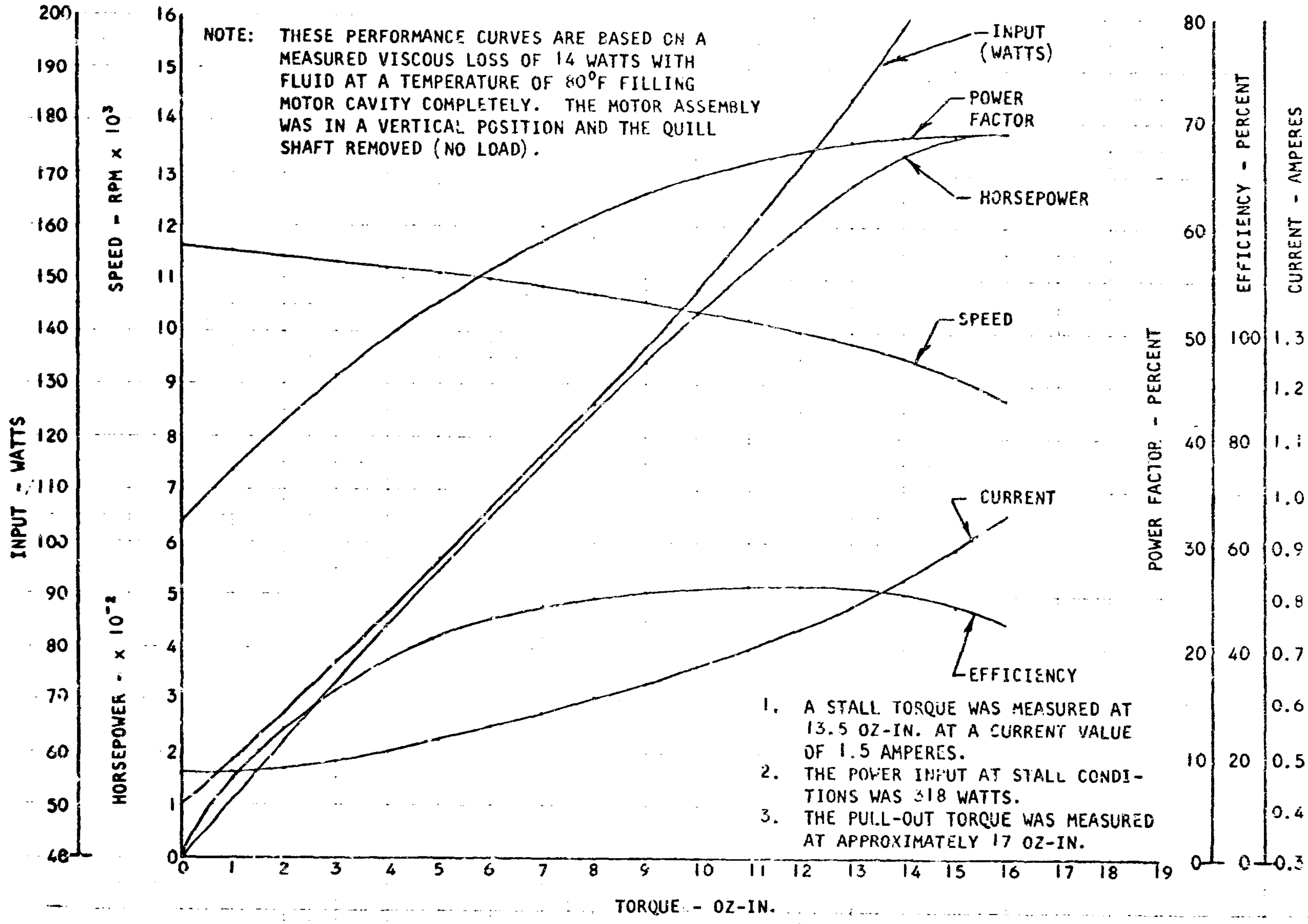

Figure 46. Estimated Motor Performance, Wet

(2) Rated three-phase voltage was then applied and recordings were made of the voltage and current transients during the starting period.

Winding Resistance - The resistance of each motor winding was measured at room temperature.

b. Results--The results of the reactance test are summarized in the following listed breakdown.

Negative Sequence Reactance

(1) Synchronous speed - 12,000 rpm

(2) Frequency, (voltage) - 400 cps

(3) Current per Phase - 0.52 amp

(4) Voltage, line-to-line - 34.0 v

Zero-Sequence Reactance

(1) Synchronous speed - 12,000 rpm

(2) Frequency (voltage) - 400 cps

(3) Current - 0.52 amp

(4) Voltage - 10.0 v

Subtransient Reactance - The peak current surged to about 2.5 amp (Phase B) in the first half-cycle of current, reducing to about 1.75 amp (peak) in the next half-cycle. As the motor came up to speed, the current reduced to the steady-state no-load running value of 0.58 amp (peak), or 0.41 amp (rms). The steady-state current is reached in 40 current cycles, or 0.1 sec.

Winding Resistance - The resistance measured at room temperature was 13.77 ohms for each winding.

3. Pump Performance Test

a. Test Specimen--The pump performance test was conducted on a pump and accumulator assembly, essentially one-half of a dual-pump package.

b. Procedure--The performance test was conducted at constant voltage (115/200 v, ±1.0 percent) and frequency (400 cps, ±0.25 percent). Sufficient data points were taken to define pump-motor performance at temperatures of -5^0 to 100^0F, in the inlet pressure range between 5 and 25 psia, and with pressure rises of 40 to 160 psi. Bypass valve settings of "fully closed" and of "nominal pilot compartment loop flow" (5.43 ± 0.3 lb per min) were used.

The data taken were sufficient for the calculation of power input to the motor. Pressures, fluid temperatures, fluid flows, and motor case temperature were logged.

c. Results--At a maximum compartment heat load, in which the estimated glycol inlet temperature is 100°F at a flow rate of 5.42 lb per min, the power consumption is just below 100 w. Under a failed-compartment condition, during which the glycol inlet temperature may drop to -5°F (the lower end of the glycol temperature control band), the pump power consumption is approximately 196 w for a glycol flow of 5.5 lb per min. The test results are plotted in Figure 49.

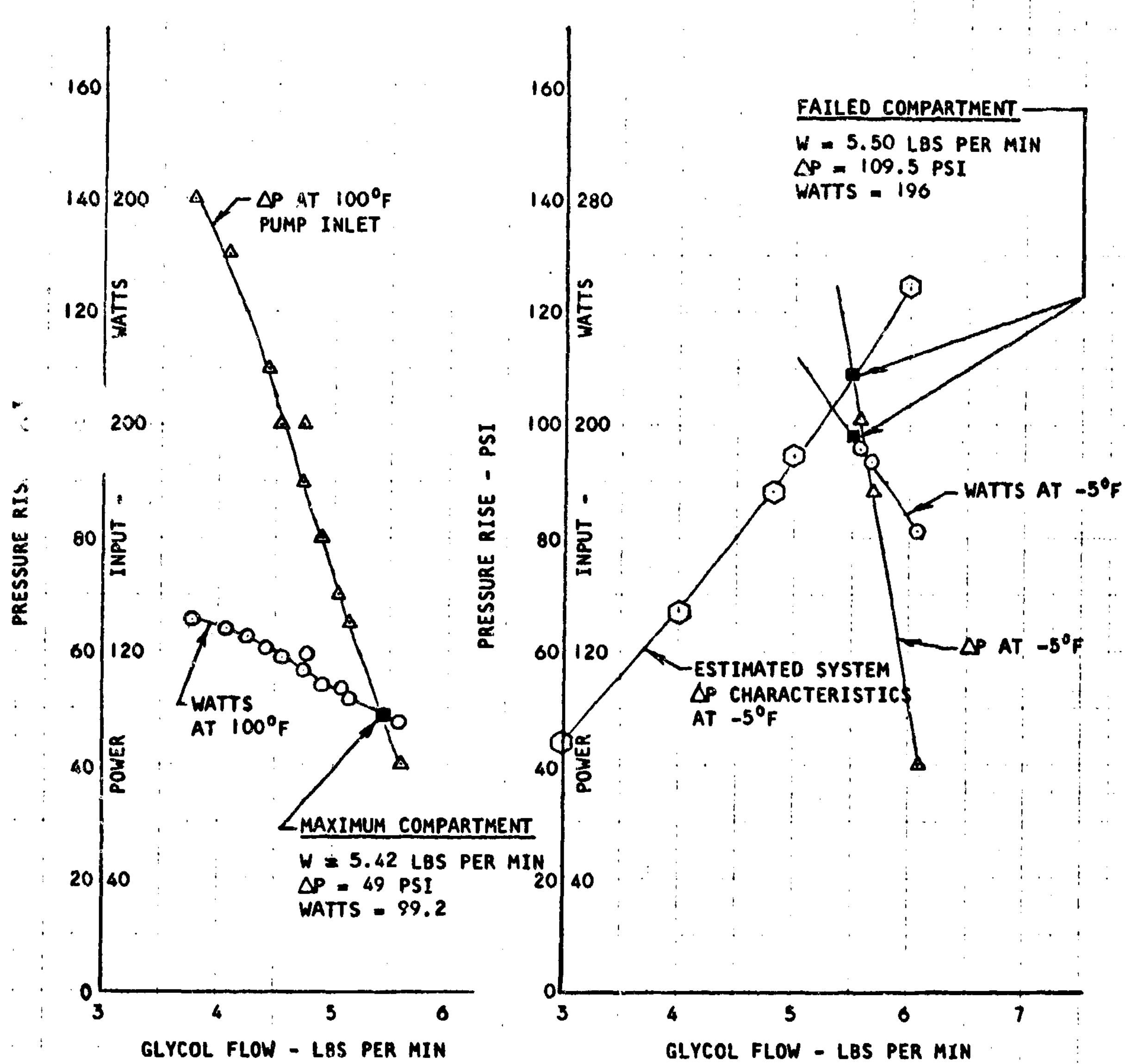

Figure 49. Pump Performance

THE -8 PACKAGE, GLYCOL TEMPERATURE AND HYDROGEN PRESSURE CONTROL UNIT 179140-1-1

Description

1. Package Function

The -8 package is by far the largest, the most complex, and certainly the most vital package of the Dyna-Soar thermal management system. Briefly, the package removes heat from, and regulates the discharge temperature of, the system's two glycol heat transport loops; and regulates the internal pressure of the vehicle supercritical hydrogen storage tank. It accomplishes these functions while also ensuring an adequate supply of hydrogen as fuel to the vehicle auxiliary power units (APU's) under steady-state or transient fuel demands.

The package also provides a stable flow of recirculating cryogenic hydrogen to the hydrogen storage tank to prevent temperature stratification of the hydrogen supply, and provides for relief of hydrogen tank pressure if this should become excessive.

Glycol temperature regulation is accomplished by modulating hydrogen flow through a glycol-to-hydrogen heat exchanger on its way to the APU. When the flow required for the cooling load exceeds the APU fuel-feed requirement, the excess required for cooling is obtained by venting hydrogen overboard. When the APU flow requirement is greater than that required for glycol cooling, the additional hydrogen for fuel is bypassed around the heat exchanger.

Hydrogen tank pressure regulation is accomplished by transfer of some heat from the cooling load into the hydrogen tank. The heat is obtained by tapping off a regulated amount of warm hydrogen from the discharge side of the glycol-to-hydrogen changer. Heat is transferred from the warm hydrogen to the cold-tank hydrogen circulating in an insulated loop external to the tank. The warm hydrogen is then returned to the inlet side of the glycol-to-hydrogen heat exchanger.

2. Physical Features

The complete package is shown in Figure 50. The outline configuration is shown on Drawing 179140 and the installation dimensions are shown on Envelope Drawing SK 44514, which are submitted separately.

As shown, the components are all packaged within a structural frame made of aluminum angle sections. The frame shown in the photographs is larger than the original Dyna-Soar envelope for this package in order to facilitate parts replacement, experimentation, etc., during tests. The first unit to be shipped was packaged in the original-envelope frame, but had been tested in the expanded frame.

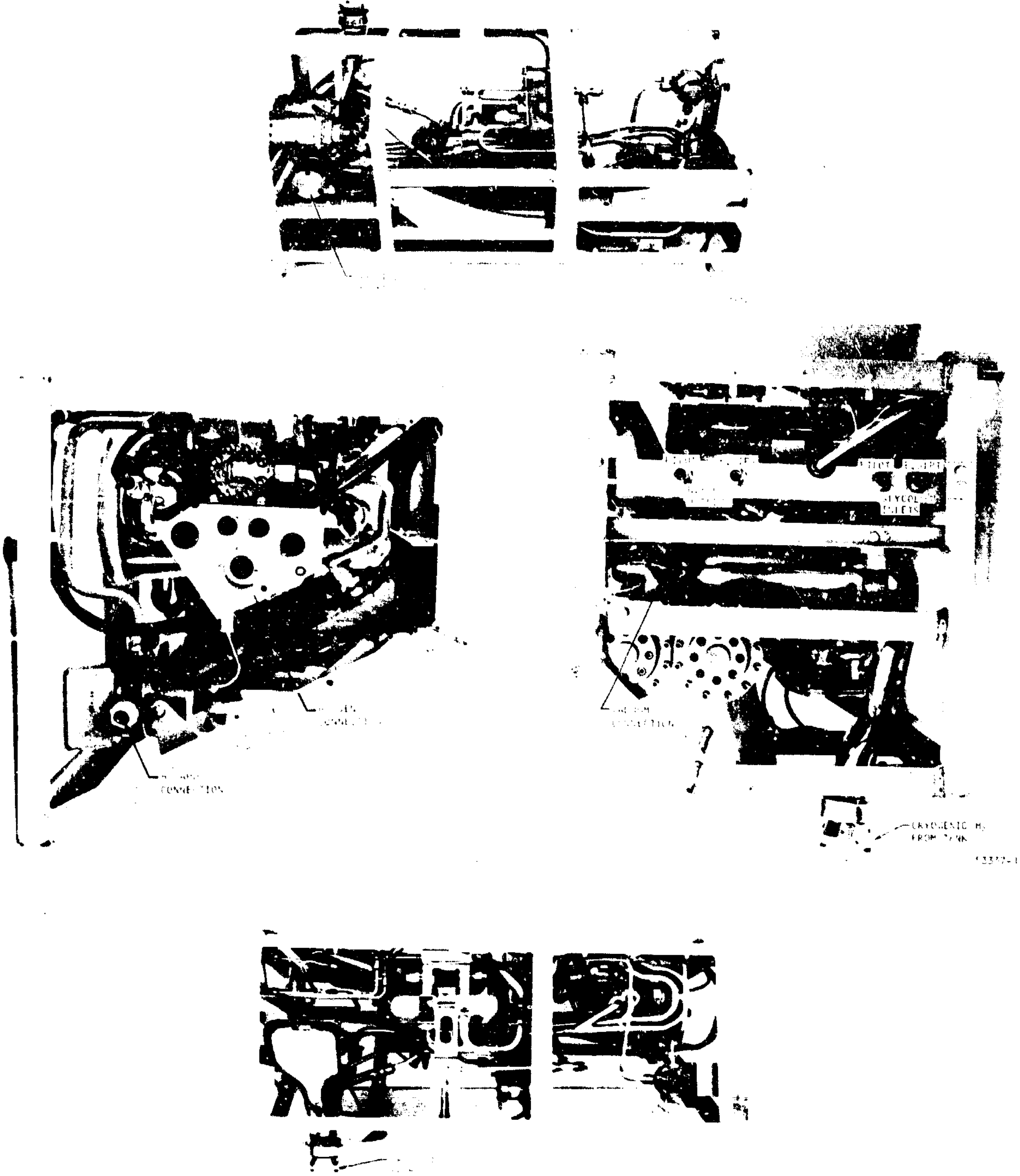

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Figure 50. -8 Package

The full complement of components without the frame is shown in Figure 51. The location of the control components in the frame is shown in Figure 52, which was taken before the heat exchangers, the rotating machinery, and the plumbing and wiring were installed. The location of these latter items can be seen in the views of the complete package, Figure 50.

3. Component Descriptions

To describe the package operation in greater detail, the description has been arranged by components. For this purpose, the components are considered as belonging to the following groups, determined roughly by function:

a. Primary recirculation loop

b. Hydrogen control valve group

c. Differential pressure limiter

d. Tank pressurization group

e. Electronic controls

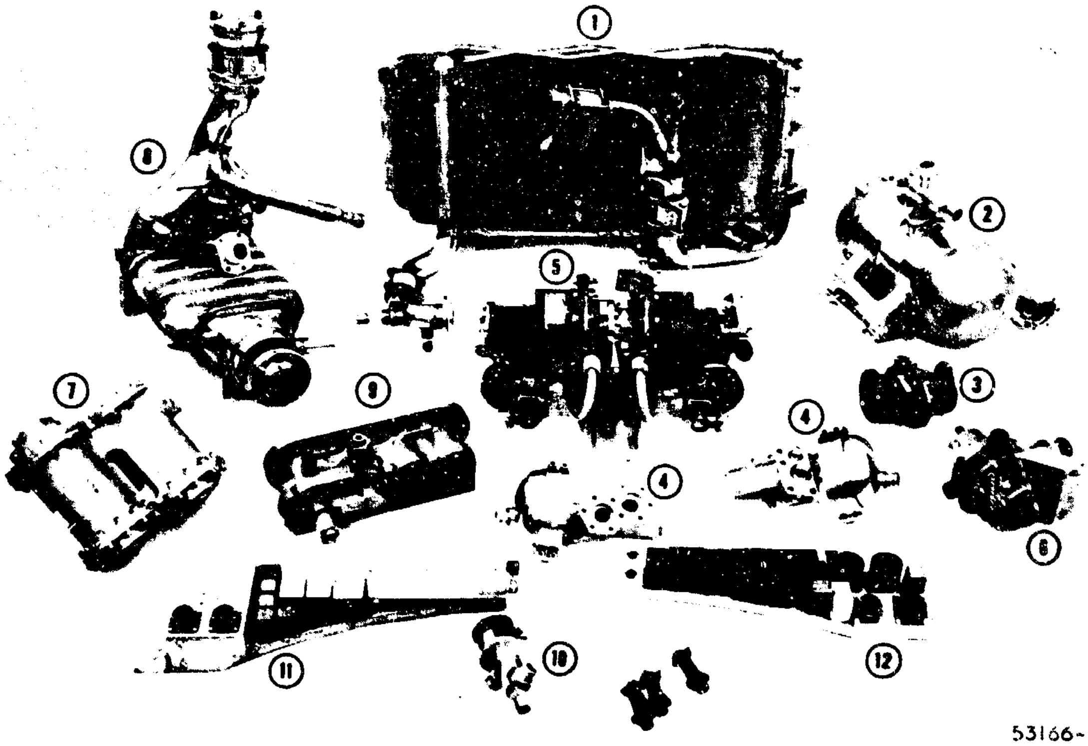
Although the component and group descriptions are individually illustrated, it may be helpful to refer to the complete package schematic, Figure 53, to visualize the relationships between groups.

4. Primary Recirculation Loop

a. The Loop as a Whole--The glycol-to-hydrogen heat exchanger, the hydrogen flow control, and the dual recirculation compressor and check valve form a recirculation loop, open at two ends as shown in Figure 54. A photograph of the units assembled together is shown in Figure 55.

The loop receives cold, supercritical hydrogen from the tank and delivers warmed hydrogen at a slightly higher pressure to the glycol temperature control and hydrogen tank pressurization components. In the process, it removes heat from the glycol heat-transport fluid which circulates through the other system packages.

This function alone could be accomplished by the compressor and the heat exchanger without the recirculation path. The recirculation line returns a portion of the warm hydrogen from the heat exchanger outlet to a mixing tee at the compressor inlet. The warm hydrogen mixes with the cold hydrogen withdrawn from the tank to maintain the heat exchanger inlet temperature above that which could cause freezing of the glycol. This temperature is normally between $-100^{\circ}F$ and $0^{\circ}F$.



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(1) GLYCOL-TO-HYDROGEN HEAT EXCHANGER (PRIMARY HEAT EXCHANGER)

(2) DUAL RECIRCULATION COMPRESSOR AND CHECK VALVE

(3) HYDROGEN FLOW CONTROL

(4) GLYCOL TEMPERATURE REGULATING VALVES (NORMAL AND STANDBY)

(5) HYDROGEN CONTROL, INCLUDES:

a. NORMAL AND STANDBY DIFFERENTIAL PRESSURE REGULATORS
b. NORMAL AND STANDBY ELECTRO-PNEUMATIC SELECTOR VALVES
c. DUAL OUTLET CHECK VALVE

(6) DIFFERENTIAL PRESSURE LIMITER VALVE

(7) ABSOLUTE PRESSURE REGULATOR

(8) DUAL PRESSURIZATION HEAT EXCHANGER AND FAN

(9) PNEUMATIC RELIEF VALVE

(10) GLYCOL TEMPERATURE SENSOR

(11) GLYCOL TEMPERATURE CONTROLLER

(12) GLYCOL SYSTEM SELECTION CONTROLLER

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Figure 51. Components of the -8 Package

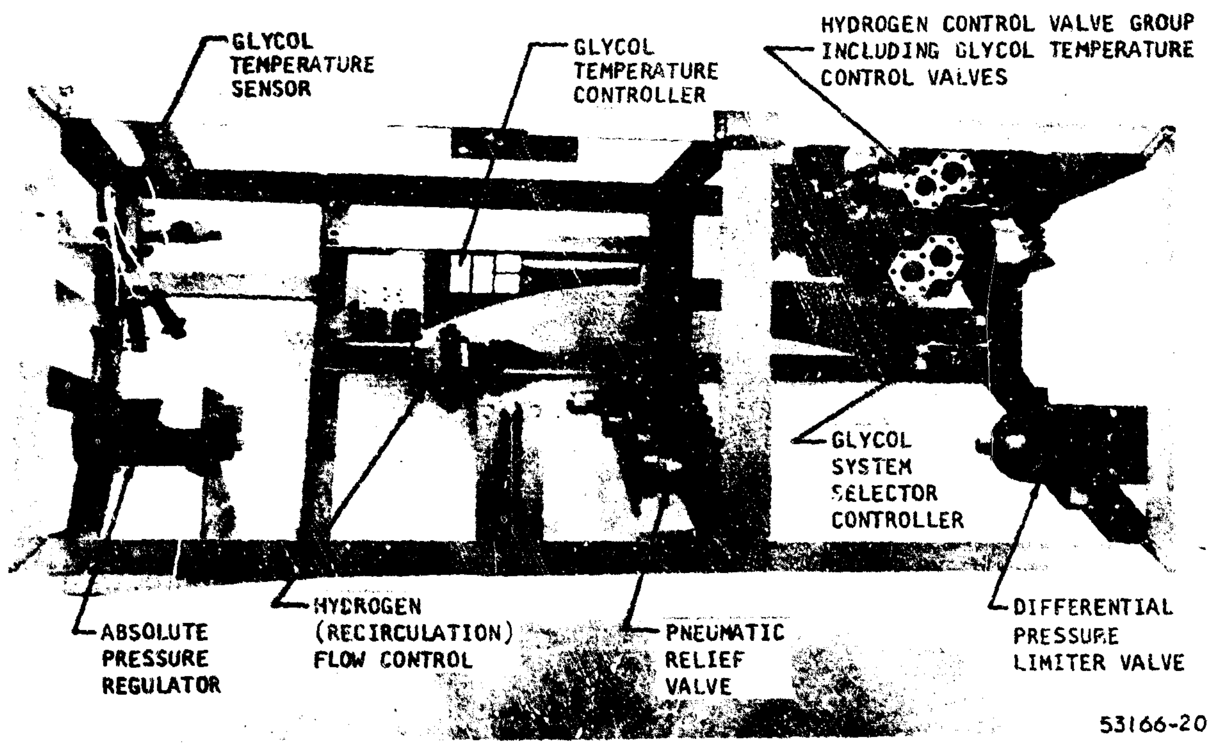

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Figure 52. Location of the Control Components in the Frame

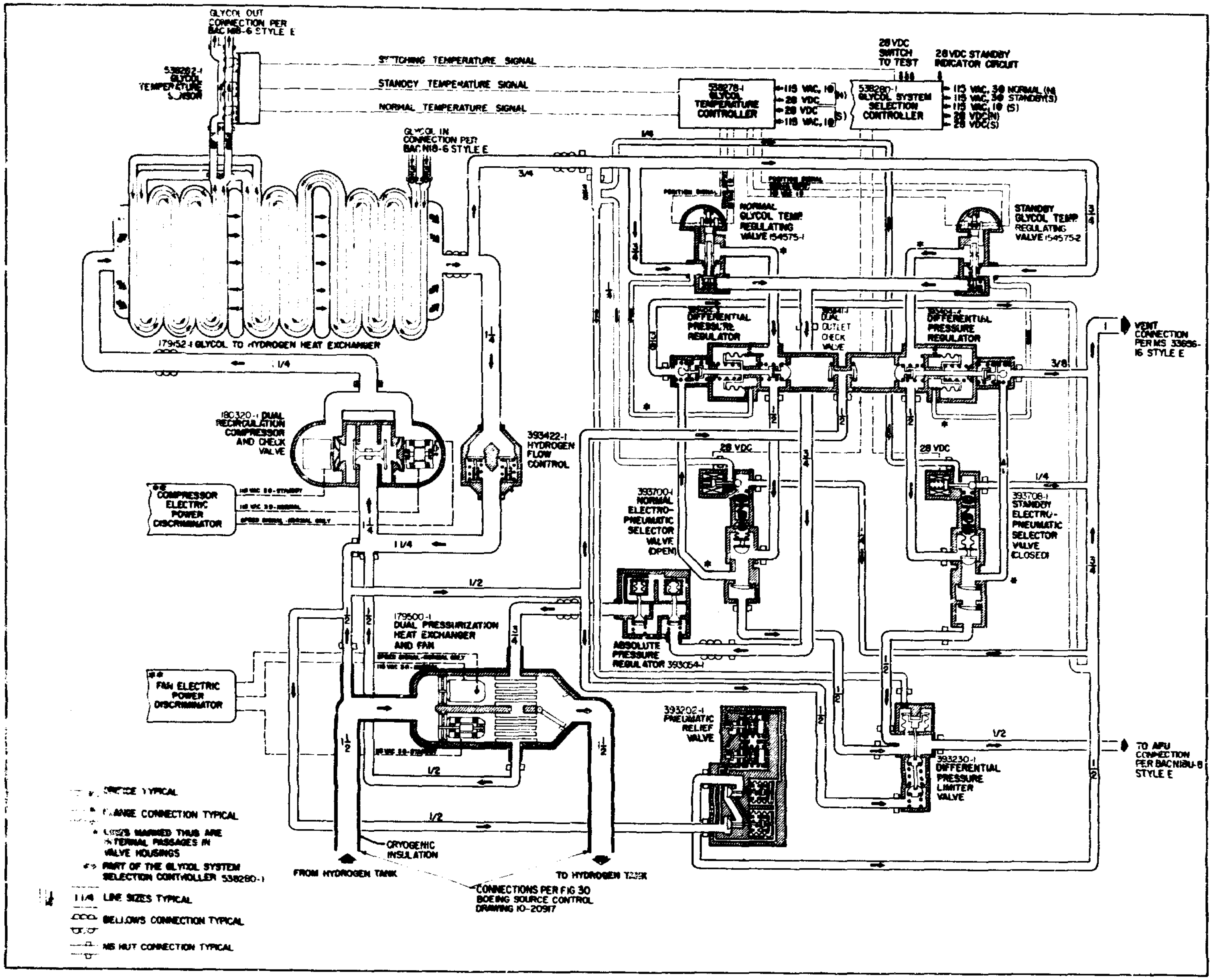

Figure 53. Package Schematic

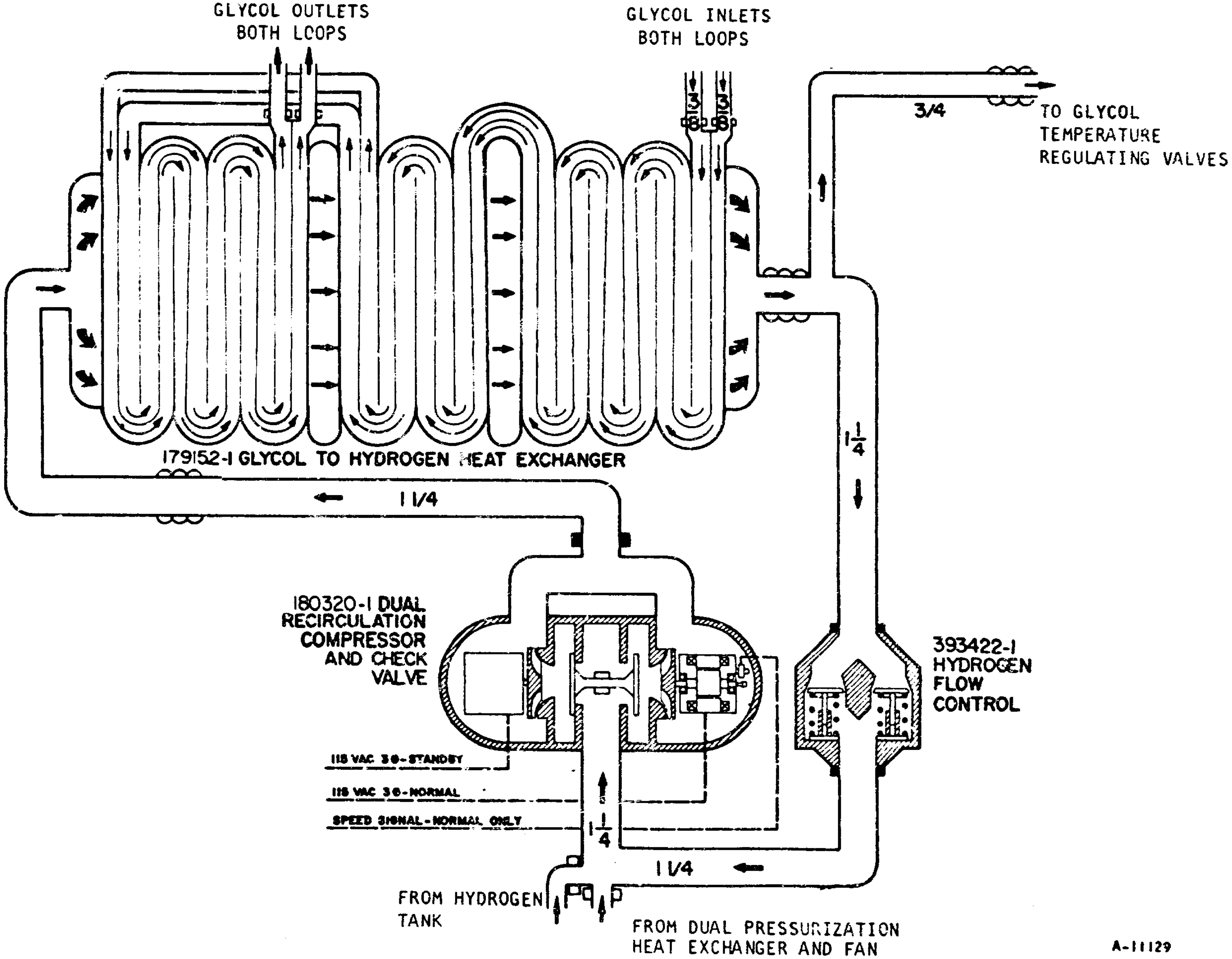

Figure 54. Primary Recirculation Loop Schematic

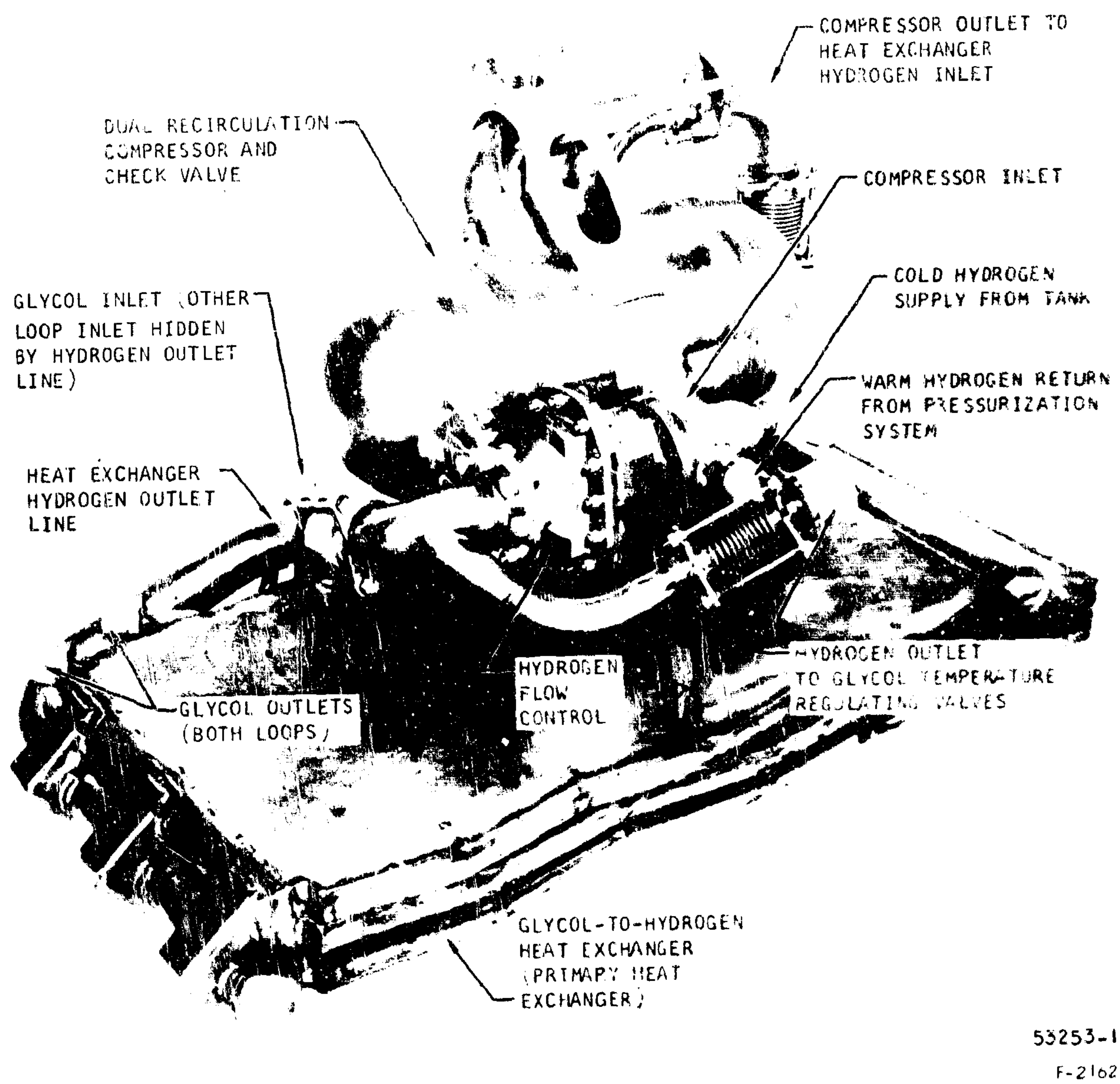

Figure 55. Primary Recirculation Loop

The recirculation flow is controlled, not by temperature requirements, but by the need to maintain a nearly constant compressor flow of 1.64 lb per min. Therefore, at high heat loads when the hydrogen throughflow may be 0.8 lb per min or more (flow is choke-limited to 1.3 lb per min by the temperature control group), the recirculation flow is only about half the total flow, and the heat exchanger inlet temperature approaches -100°F. Under low-heat-load conditions, when the throughflow may drop to 0.2 lb per min, or less (the package is capable of complete shutoff of cooling hydrogen), the proportion of recirculation flow is much higher, and the heat exchanger inlet temperature approches 0°F.

b. Glycol-to-Hydrogen Heat Exchanger (Primary Heat Exchanger)--This unique plate-fin heat exchanger consists of three thin, flat sections joined at the hydrogen headers as shown in Figure 55. The unusual shape is necessary to ensure proper fluid distribution and to provide a single plate-fin passage for each glycol loop as protection against freezing. By elimination of parallel glycol flow paths, the possibility of preferential flow, and possible congealing of the starved passages, is eliminated. The positive displacement pump described earlier in this report ensures that all surfaces are swept by fresh glycol.

The two glycol loops--the pilot compartment loop and the equipment compartment loop--are kept separate, but adjacent to a common wall, throughout all sections of the heat exchanger. Heat transfer through the common wall between glycol loops results in both loops emerging from the heat exchanger at the same temperature regardless of their inlet temperature difference.

The two glycol passages are sandwiched between two outer hydrogen passages as shown in the cutaway sketch, Figure 56. The hydrogen divides into two parallel passages and makes one straight pass through each section, the two passages mixing in the headers at the end of each section. The glycol of each loop makes six cross-counterflow passes in each of the first two sections and six cross-parallel-flow passes in the third section. The hydrogen enters the heat exchanger in the cross-parallel-flow section and exits the heat exchanger from the cross-counterflow section.

The cross-counterflow section provides the high hydrogen-side effectiveness needed to conserve hydrogen, while the cross-parallel-flow section reduces the possibility of glycol freezing. In the cross-parallel-flow configuration, the glycol and hydrogen enter the same end of the heat exchanger, resulting in higher wall temperatures than would occur under cross-counterflow.

Further protection against glycol freezing is provided in the hydrogen inlet section (cross-parallel-flow section) by an insulating, or buffer, zone interposed between the glycol and hydrogen walls. The buffer zone consists of a sealed, finned passage containing trapped ambient air.

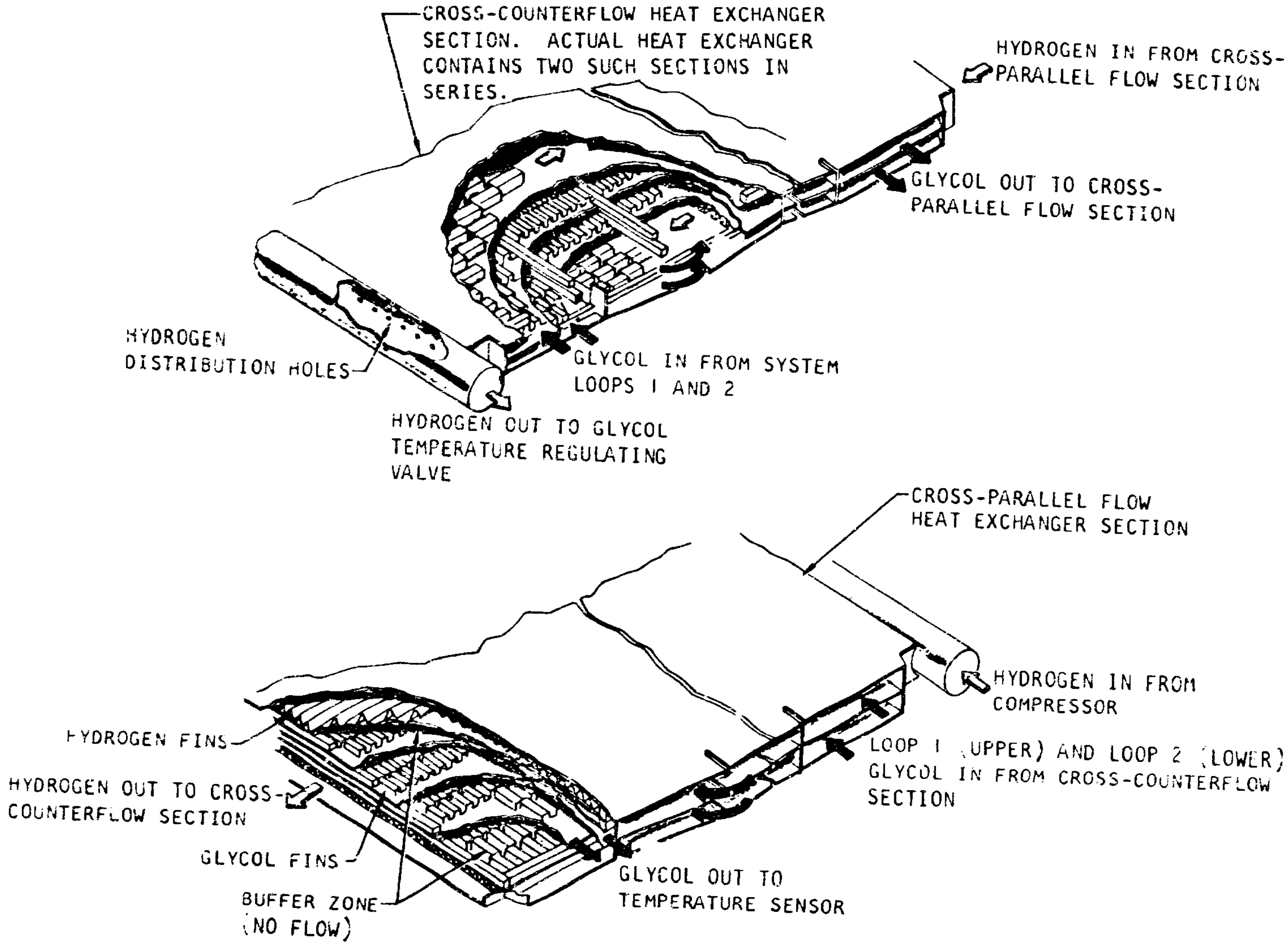

Figure 56. Primary Heat Exchanger

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The foregoing has been a general description of the heat exchanger. The following paragraphs describe the construction details for the cross-parallel-flow and cross-counterflow sections.

The cross-parallel-flow section is a plate-fin matrix consisting of six internally finned passages. Starting from the center of the matrix, with respect to the no-flow dimension, the two innermost passages are used for the two glycol-water fluid flow loops. Continuing out from the center, the next two passages are insulating buffer layers and, finally, the two outer passages, adjacent to the side plates, are for hydrogen fluid flow. The two separate glycol-water fluid loops are in parallel, each making six passes, in cross-parallel flow with the hydrogen fluid flow. The hydrogen makes one straight pass through the section, mixing in the outlet manifold and continuing on to the second section. The fin types used and significant dimensions are listed below:

	Glycol	Buffer	Hydrogen
Number of passes (each loop)	6	1	1
Pass width, in.	3	8	8
Pass length, in.	8	12.5	12.5
Fin material	Copper	Nickel	Nickel
Fin type	Rectangular-offset	Triangular	Triangular
Fins per inch	16	26	17
Uninterrupted fin length, in.	0.125	Plain	2.50
Fin thickness, in.	0 005	0.006	0.004
Plate spacing, in.	0.10	0.10	0.10
Plate thickness, in.	0.032	0.008	0.008

Generally, the construction of the cross-counterflow sections is the same as in the cross-parallel-flow section, the major differences being the absence of a buffer passage and the employment of a high-performance fin on the hydrogen side. The fin types used and the significant dimensions are listed below:

	Glycol	Hydrogen
Number of passes (each loop)	12	1
Pass width, in.	3	8
Pass length, in.	8	37.5
Fin material	Copper	Nickel
Fin type	Rectangular-offset	Rectangular-offset
Fins per inch	16	16
Uninterrupted fin length, in.	0.125	0.143
Fin thickness, in.	0.005	0.004
Plate spacing, in.	0.10	0.153
Plate thickness, in.	0.032	0.008

Type 316L corrosion resistant steel was selected for tube plates, side plates, and reinforcement strips. Type 321 corrosion resistant steel was used for pans, manifolds, and fittings. The three core sections were vacuum-brazed at 1960°F using nickel brazing alloy per AMS 4777. Pans, manifolds, and fittings were attac[illegible] by tungsten-inert-gas (TIG) welding in accordance with AiResearch Specif[illegible]tion WBS-18.

Uniform hydrogen flow distribution is obtained in each of the three core sections by placing a series of orifices at the inlet to each core. Entrance jet effects on the glycol-water side have been reduced by directing the inlet jet against the common tube plate, dissipating the velocity head before entering the tube passage.

c. Dual Recirculation Compressor and Check Valve--As mentioned in the primary recirculation loop description, the head rise required for both primary heat exchanger recirculation and pressurization loop operation (circulation) is produced by the dual recirculation compressor and check valve, pictured in Figure 57. This unit consists of two single-stage compressors mounted face-to-face, sharing a common inlet plenum, as shown schematically in Figure 58.

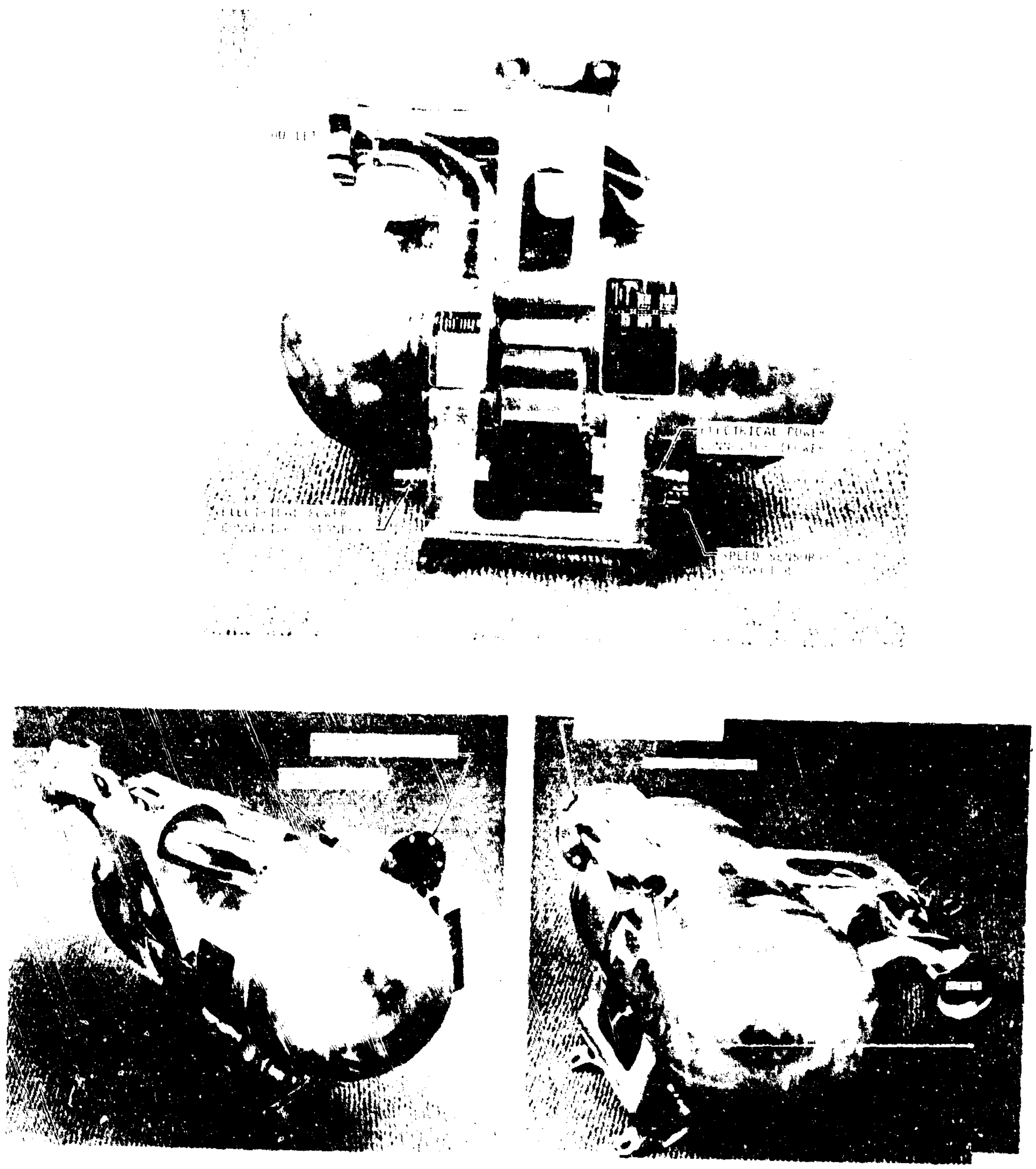

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Figure 57. Dual Recirculation Compressor and Check Valve

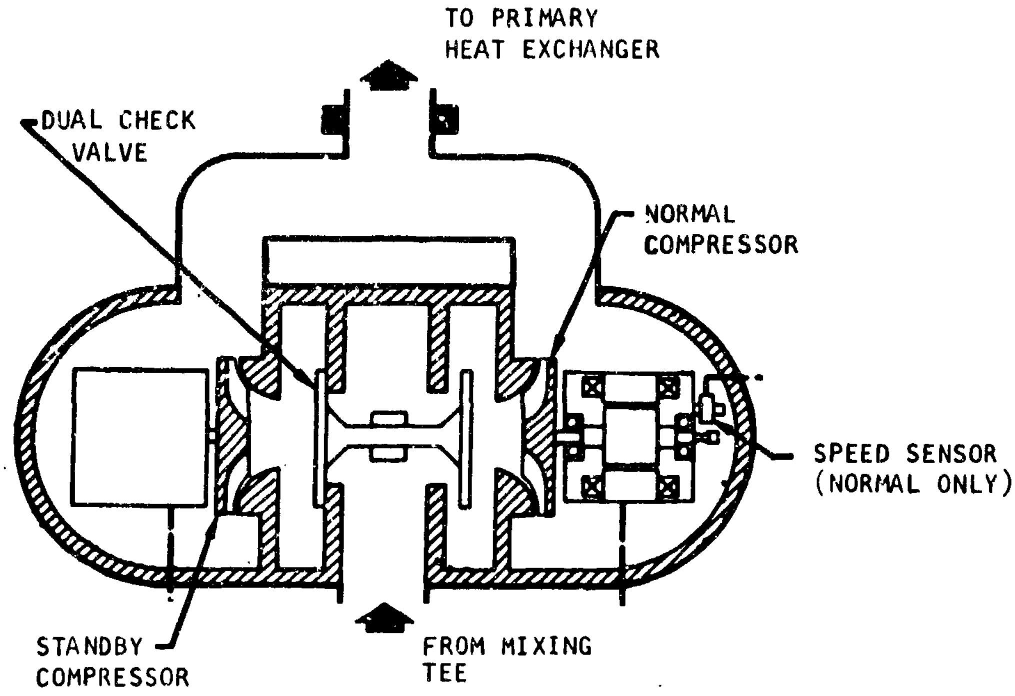

Figure 58. Dual Compressor and Check Valve

The two compressors are designated as normal and standby units, respectively. The normal unit is used exclusively until a drop in speed or a failure of normal power triggers a switchover to the standby unit. For test purposes, operation can be switched to either compressor manually. The two compressors are identical to each other, except that the normal compressor motor includes a magnetic speed pickup, the output of which is continuously monitored by the system selector for evidence of speed drop-off. The operation of the system selector is described separately. Since only one compressor is in use at any one time, the inlet plenum contains a double-poppet, double-seat check valve to isolate the idle compressor. The assembly details of the compressor and check valve are shown in Figure 59. Only one compressor is shown for simplicity. A photo of one compressor removed from the housing is shown in Figure 60.

The compressor is a single-stage, radial-flow impeller driven by a two-pole, three-phase, 400-cps, 115/200-v induction motor. The motor and impeller are completely enclosed in a sealed housing, so that the motor and bearings are immersed in and cooled by hydrogen. The bearings have stainless steel balls and Rulon separators. They are supported in special AiResearch-designed resilient mounts. The bearings are lubricated only by the hydrogen.

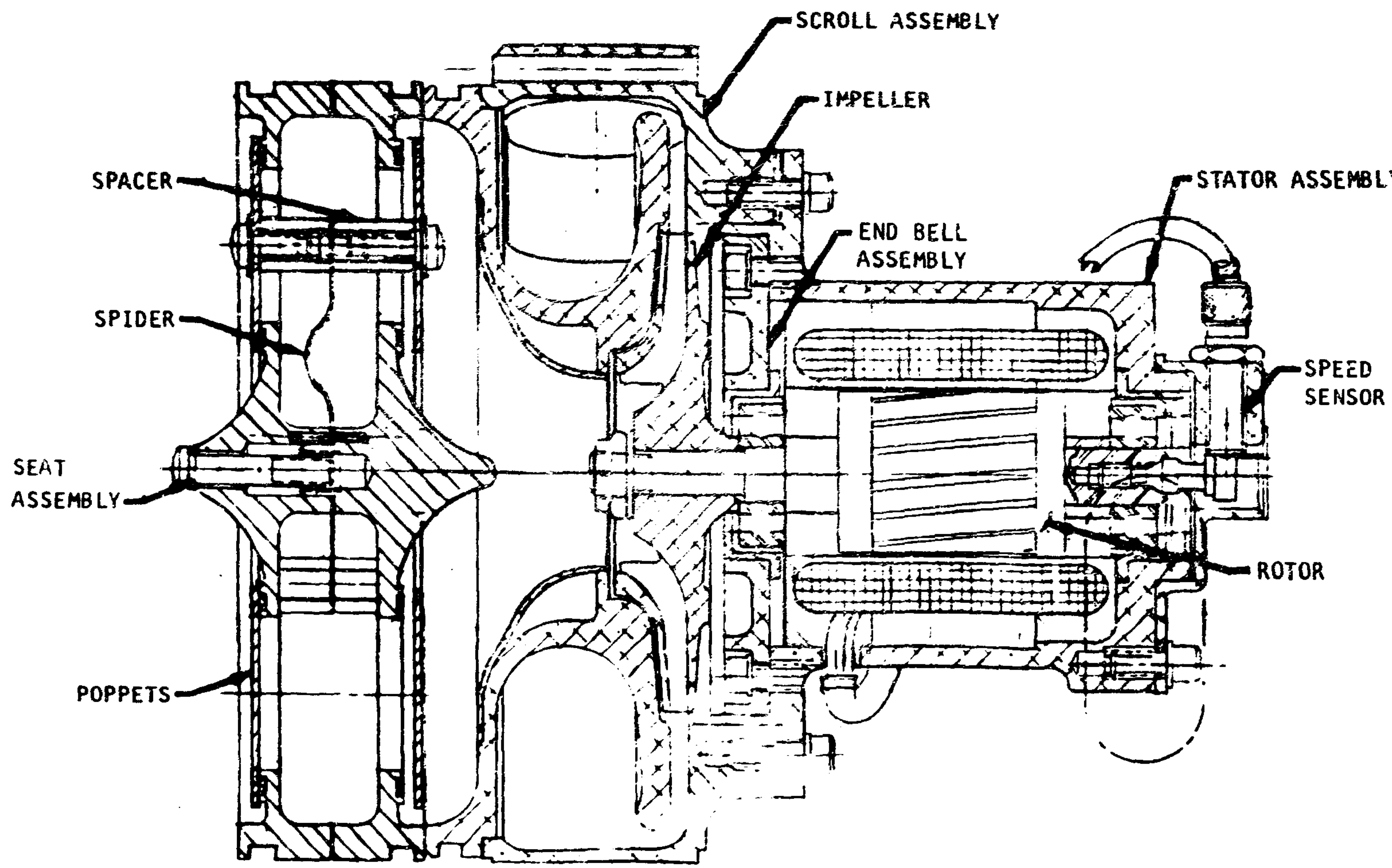

Figure 59. Normal Compressor with Check Valve

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Figure 60. Normal Compressor

The check valve is also a special AiResearch development. To eliminate static friction or binding, the poppet has no stem. It is supported by a flexible spider, which permits frictionless transfer between normal and standby seating positions regardless of concentricity or alignment. The contains a very effective, soft, lip-seal developed for use at cryogenic temperatures.

d. Hydrogen Flow Control--The hydrogen flow control provides sufficient recirculation flow to maintain a reasonably constant hydrogen flow through the compressor and heat exchanger regardless of the "throughflow" or withdrawal rate. It does this by maintaining a nearly constant pressure differential between the compressor inlet and the heat exchanger outlet. Since precise regulation is not required, the control consists of a pair of simple spring-loaded flat poppets, or "buttons", as shown in the following sketch, Figure 61.

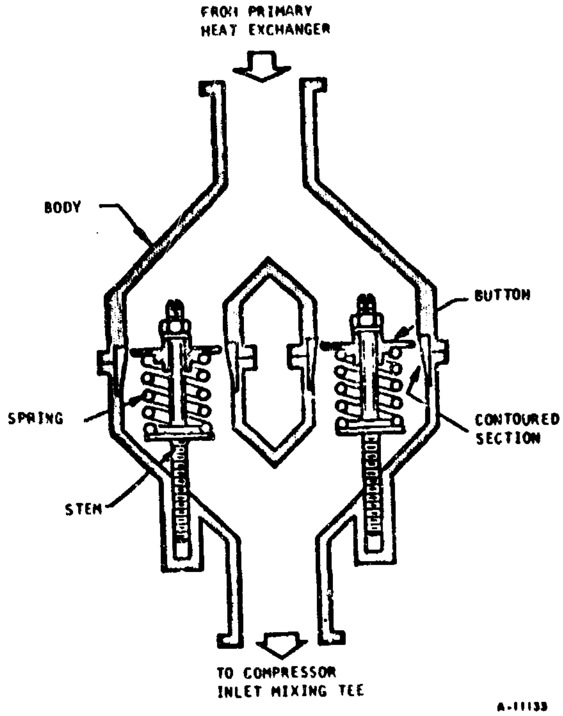

Figure 61. Hydrogen Flow Control Schematic

Pressure differential positions the buttons in the contoured section to provide the area required to pass the desired flow rate. The redundancy in poppets is for reliability. Although designed for regulated flow through both passages, the valve will still provide a fair degree of regulation if one of these buttons should fail in either the fully open or fully restricted position. The exterior of the flow control is shown in Figure 62.

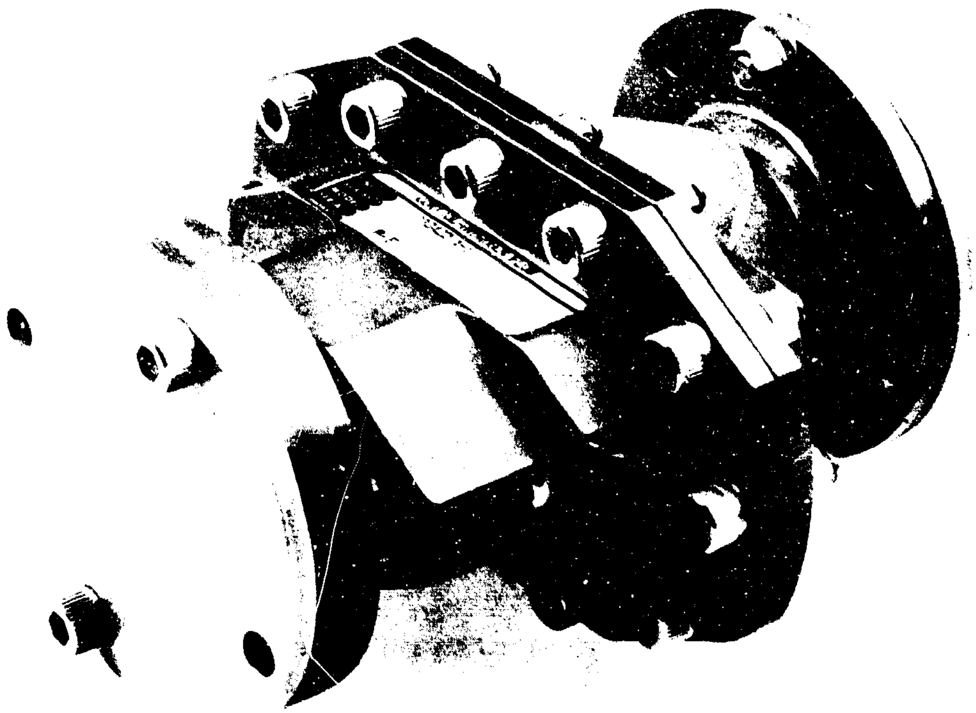

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Figure 62. Hydrogen Flow Control

5. Hydrogen Control Valve Group

a. The Group as a Whole--The valves directly involved in hydrogen flow management are the glycol temperature regulating valve, the differential pressure regulator, the electropneumatic selector valve, and the dual-outlet check valve. The pneumatic interconnection between these valves is shown in Figure 63, excerpted from the package schematic. The electrical interconnection will be explained in the separate discussion of the electronic components.

As shown in the schematic, the valves are arranged in two identical and completely redundant groups, a normal group and a standby group. The differential pressure regulator and the electropneumatic selector are housed in a single casting. The normal and standby versions are joined by the dual-outlet check valve into the nearly symmetrical assembly pictured in Figure 64 and known as the hydrogen control. The group is completed by the addition of the normal and standby glycol temperature regulating valves. Three views of the complete group are shown in Figure 65.

The group receives warm hydrogen from the heat exchanger and cold hydrogen directly from the tank, and discharges hydrogen to the vehicle auxiliary power unit (APU), an overboard vent, and to the pressurization group.

The basic function of the temperature control group is to manage the hydrogen flow in such a way as to accommodate both the glycol cooling load and the vehicle auxiliary power unit (APU) fuel demand. When APU flow demand exceeds the cooling load demand, the valve group furnishes additional hydrogen directly from the tank, bypassing the heat exchanger. When the cooling demand exceeds the APU demand, the valve group vents the excess overboard. The relationship to the pressurization flow is purely an override control to restrict heat exchanger throughflow to avoid subcooling the glycol. The normal metering of pressurization flow is carried out by the absolute pressure regulator, discussed separately under the pressurization group.

b. Glycol-Temperature Regulating Valve--The glycol-temperature regulating valve is a two-poppet, two-seat valve. The poppets are referred to in the discussion as the temperature control poppet and the pressurization poppet. A photograph of the valve is shown in Figure 66, and the valve assembly details are shown in Figure 67.

The poppets are positioned by an electric-motor-driven linear actuator. The motor is a two-phase servo motor, which receives its servo signal from an electronic glycol temperature controller (described separately). The flow-control poppet forms a variable restriction in the hydrogen line, thereby generating a pressure-differential pneumatic signal. The pneumatic signal is applied to the differential pressure regulator, which, in trying to maintain a constant differential across the temperature regulating valve, adjusts the rate of flow through the temperature regulating valve, and hence the throughflow through the heat exchanger.

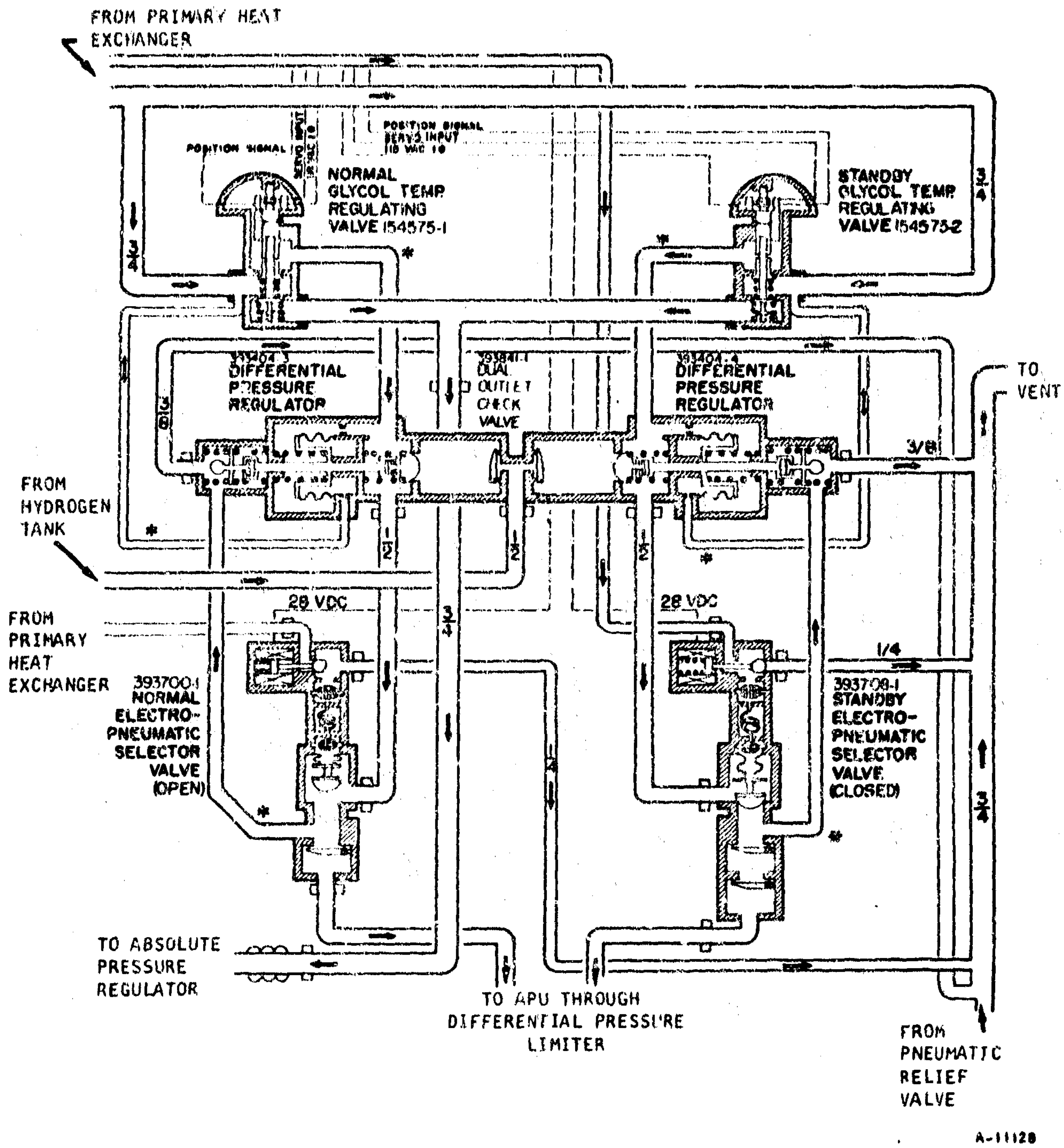

Figure 63. Hydrogen Control Valve Group

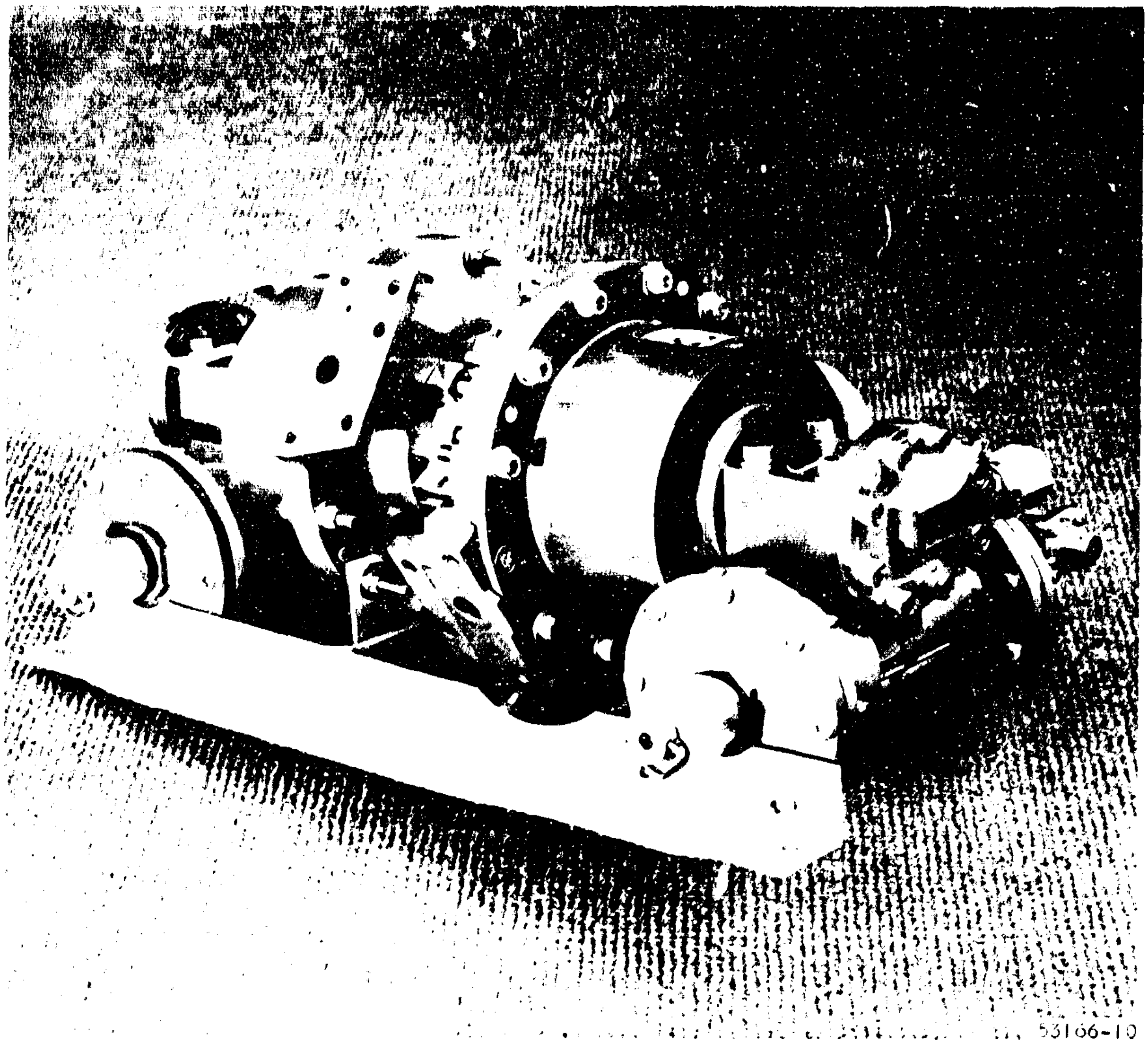

Figure 64. Hydrogen Control: Differential Pressure Regulators, Electropneumatic Selector Valves, Dual Outlet Check Valve

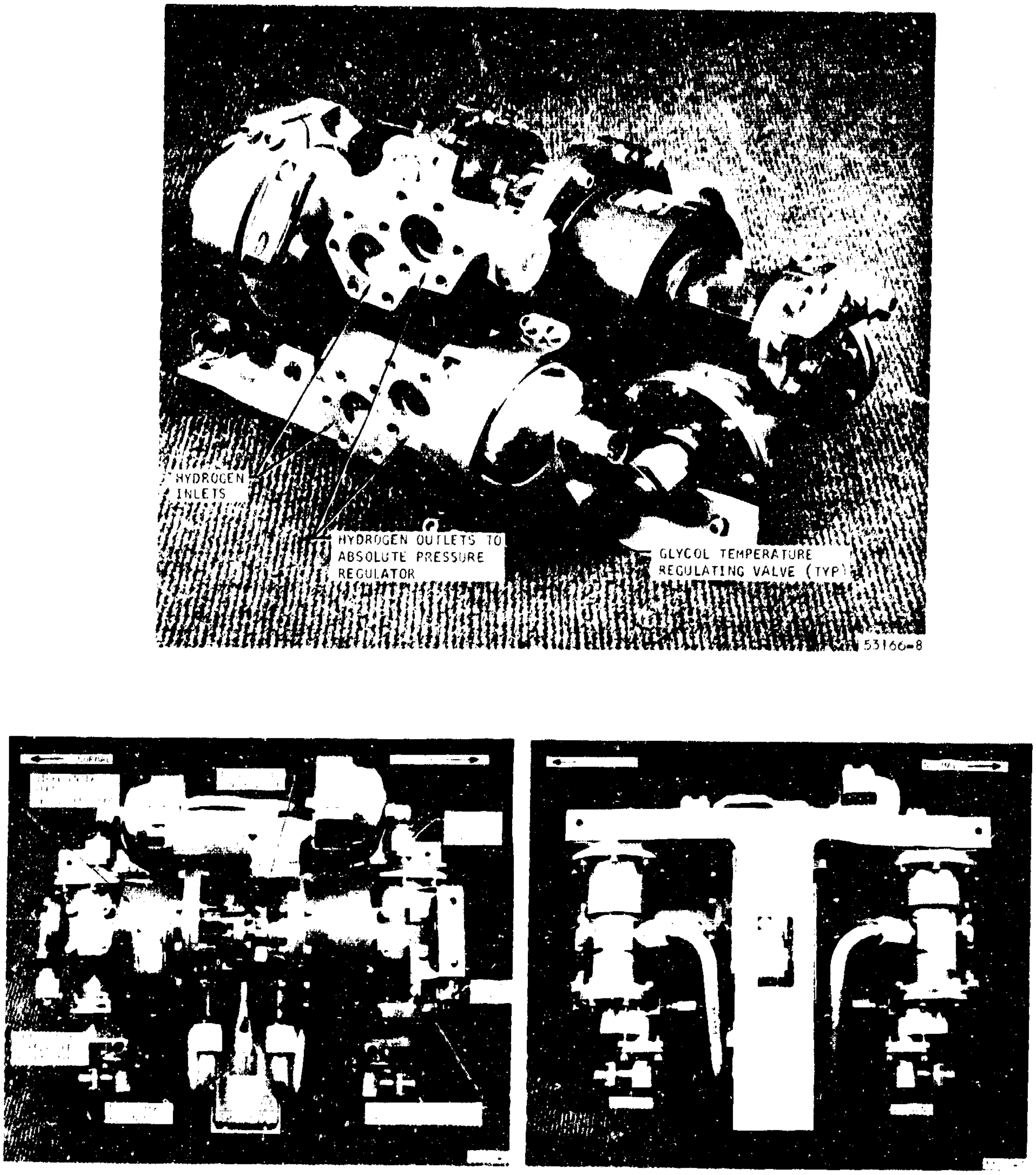

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Figure 65. Hydrogen Control Valve Group

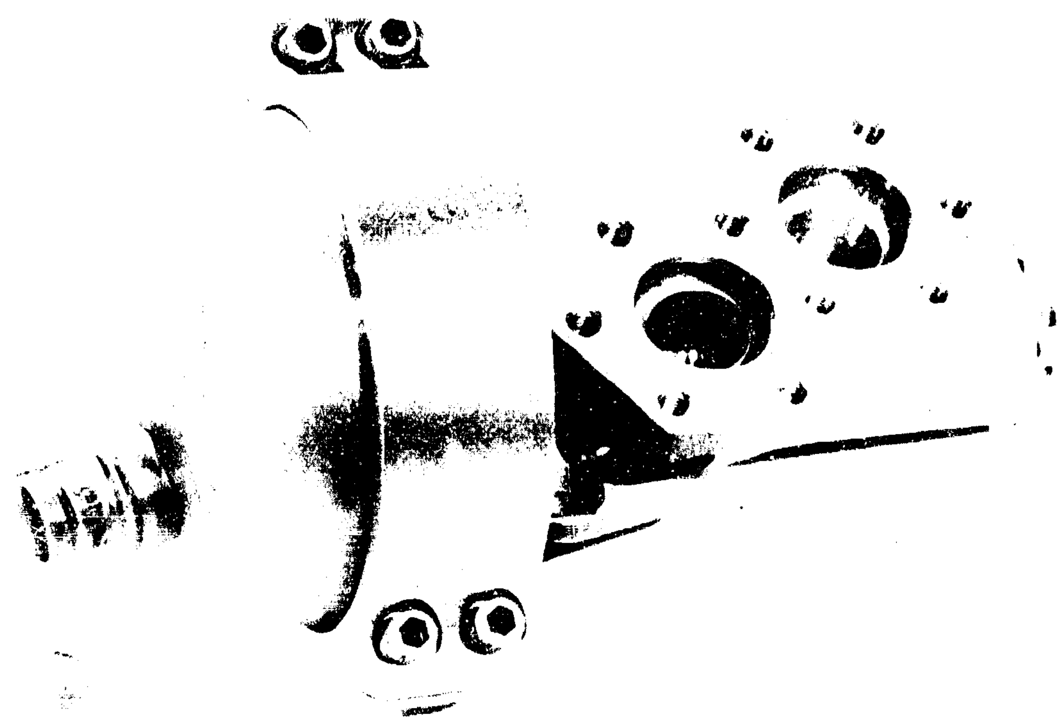

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Figure 66. Glycol Temperature Regulating Valve

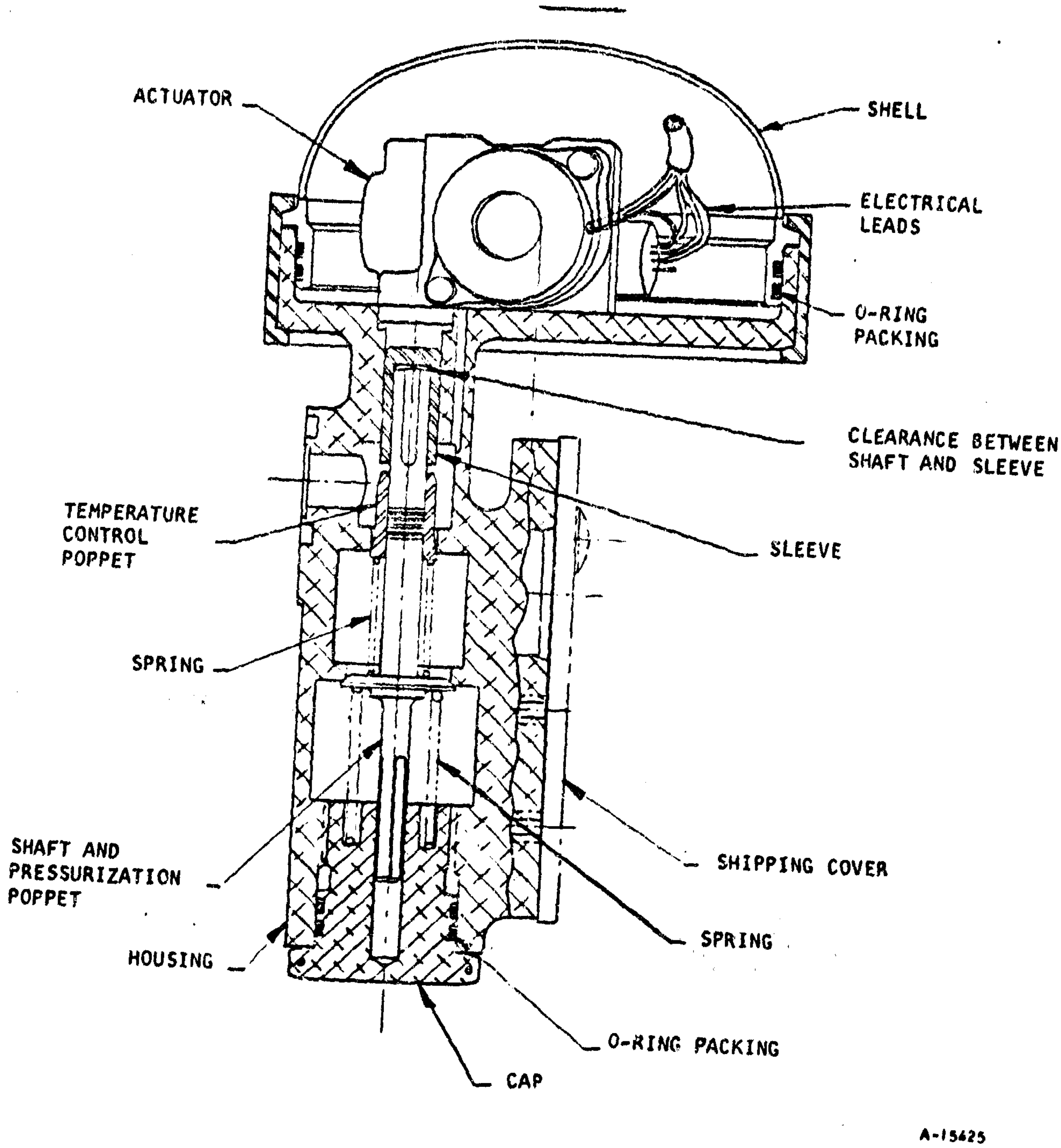


Figure 67. Glycol Temperature Regulating Valve Schematic

An increasing cooling demand (rising glycol temperature) produces an electrical signal which opens the temperature control poppet. The resulting decrease in differential pressure across the poppet actuates the differential pressure regulator in a direction tending to increase the vent flow.

A decreasing cooling load (falling glycol temperature) reverses the action. If the cooling demand decreases so far as to close the vent, the temperature control poppet then begins to regulate heat exchanger throughflow flow directly. In so doing, it applies a pneumatic signal to the differential pressure regulator, which opens the bypass poppet to admit cold hydrogen directly from the tank through the dual outlet check valve to satisfy the APU fuel needs.

Increasing APU flows will increase the pneumatic signal generated by the temperature control poppet. This actuates the differential pressure regulator to reduce the vent flow (making more hydrogen available for the APU) or, if the vent is already closed, to open the bypass to admit hydrogen directly from the tank.

The second poppet of the temperature regulating valve, the pressurization poppet, is fully open under all normal conditions. However, if the cooling demand should decrease severely, as under a low-heat-load, failed-glycol-loop condition, the pressurization poppet starts to close to restrict the flow being tapped off by the pressurization system. In an extreme condition, this poppet could be driven completely closed. This provision is necessary to prevent the pressurization demand from freezing the glycol in the heat exchanger. This preferential treatment is necessary, since the system can easily recover from low tank pressure, but may not be able to recover from a frozen heat exchanger.

c. Differential Pressure Regulator--The operation of the differential pressure regulator can be visualized by reference to the following schematic, Figure 68. The operation of this valve, which has already been explained to some extent in the description of the glycol temperature regulating valve, is enlarged on in this section.

The regulator is designed to maintain a constant pressure differential across the temperature control poppet of the glycol temperature regulator, which is subject to varying system flow demands. It does this by bypassing hydrogen directly from the tank to the APU or by venting excess cooling flow.

The major parts of this valve are a bypass poppet, a vent poppet, and a bellows and shaft assembly.

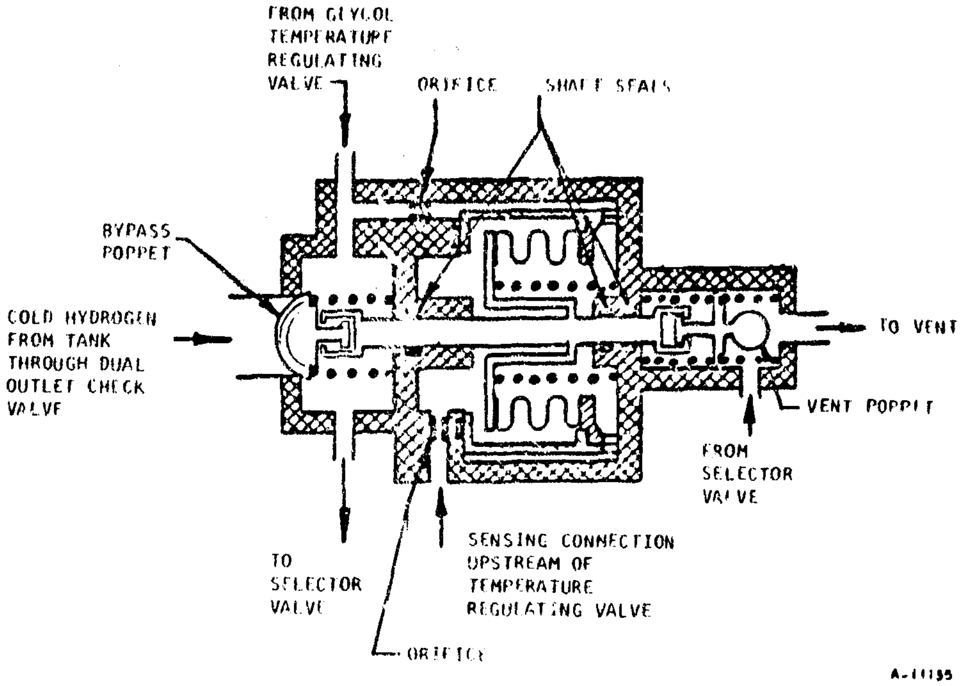


Figure 68. Differential Pressure Regulator

The pressure differential is sensed by the bellows assembly. When this differential is at the nominal value, both the vent and bypass poppets are closed. This would occur when the APU demand and the cooling demand for hydrogen are equal.

For pressure differentials in excess of the nominal, the vent valve is closed and the bypass valve is modulated open. This occurs when the APU demand exceeds the cooling demand.

For pressure differentials less than the nominal, the bypass valve is closed and the vent valve is modulated open. This occurs when the cooling demand exceeds the APU demand.

d. Electropneumatic Selector Valve--This valve is a spring-loaded, normally closed, electrically piloted shutoff valve. It is interposed between the hydrogen pressure sources and the vent and APU outlets. It serves no regulating function, but serves to activate either the normal or the standby temperature control valve group on signal from the glycol system selector.

The valve is shown schematically in Figure 69.

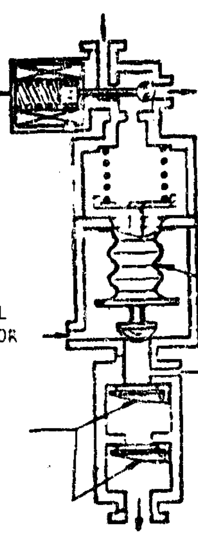


Figure 69. Standby Electropneumatic Selector Valve

When the solenoid pilot valve is de-energized, upstream pressure is admitted to the bellows interior, equalizing the pressure across the bellows. With no pressure differential across the bellows, the valve is held closed by the spring. When the solenoid is energized, the bellows interior is vented to ambient, permitting inlet pressure to force the poppet valve open.

The selector valve illustrated is the standby unit. The normal selector valve is schematically identical to the one shown, except that it has only one check valve in the outlet to the APU. This difference is the result of the design philosophy imposed by the original contractor; the philosophy was to avoid the increased weight or complexity necessitated by redundancy against double failures. The purpose of the check valves, of course, is to prevent hydrogen leakage to the vent line while the selector valve is idle (poppet closed). The need for the check valve is especially critical because such leakage might not be reflected in out-of-tolerance temperatures, and could result in considerable undetected loss of hydrogen. Since the normal selector becomes idle only as a result of a previous failure, however, check valve redundancy in the normal selector would be for double failure, and was not allowed.

e. Dual Outlet Check Valve--This unit, which has a common inlet with two outlets, is located at the junction between the normal and redundant valve groups, and allows hydrogen flow to either group directly from the hydrogen tank. The check valve is shown in the hydrogen control group photo, Figure 65, and is shown schematically in Figure 70.

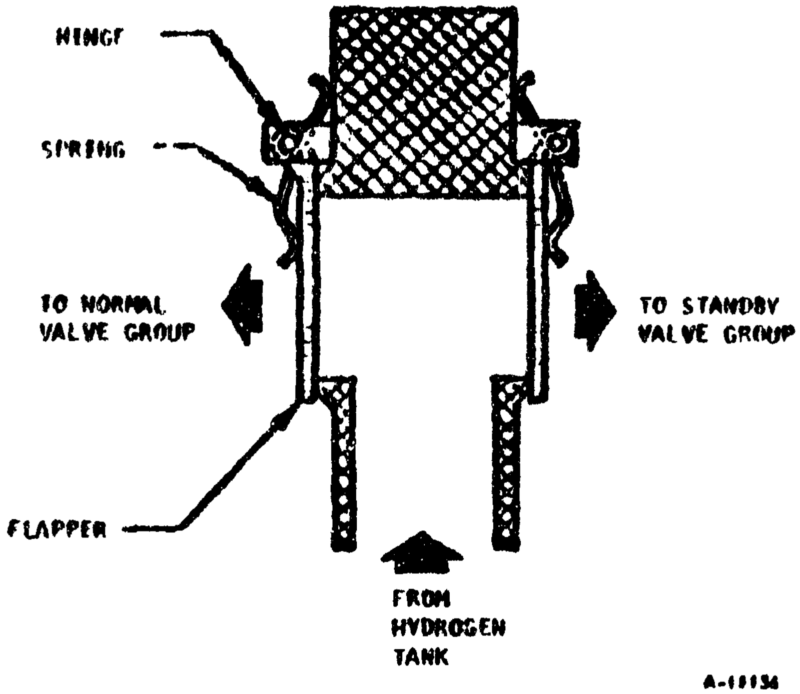


Figure 70. Dual Outlet Check Valve

As shown in the schematic, the valve consists simply of a main valve housing and two flappers hinged to the body at right angles to the direction of flow. It is part of the bypass circuit, and comes into play when the APU demand exceeds the cooling demand. It prevents backflow, which could conceivably "short-circuit" some hydrogen through the inactive temperature regulating valve back to the dual compressor inlet (see complete package schematic, Figure 53).

6. Differential Pressure Limiter Valve

This valve, which is not functionally related to any particular group, is another of the devices included solely to ensure that the APU is never starved for hydrogen. This valve, which is completely pneumatic in operation, will open to provide hydrogen flow directly from the tank to the APU when flow from the control group is stopped or unduly restricted for any reason, including even electrical power failure. The limiter valve is a holdover from an earlier nonelectronic temperature control design in which the normal-to-standby switchover and restoration of controlled hydrogen flow might have taken up to 9 sec. Although the present electronic temperature control with its rapid response eliminates this particular need, the valve was retained as a desirable safety feature. A conceivable failure in

which this valve would function is a failed bellows in the differential pressure regulator. It might be possible for the regulator bellows to fail without the glycol temperature going so far out of tolerance as to trip the system selector to standby control. The vent poppet would be fully open and the pressure at the APU supply line would drop. The differential pressure limiter would then open to provide the needed flow.

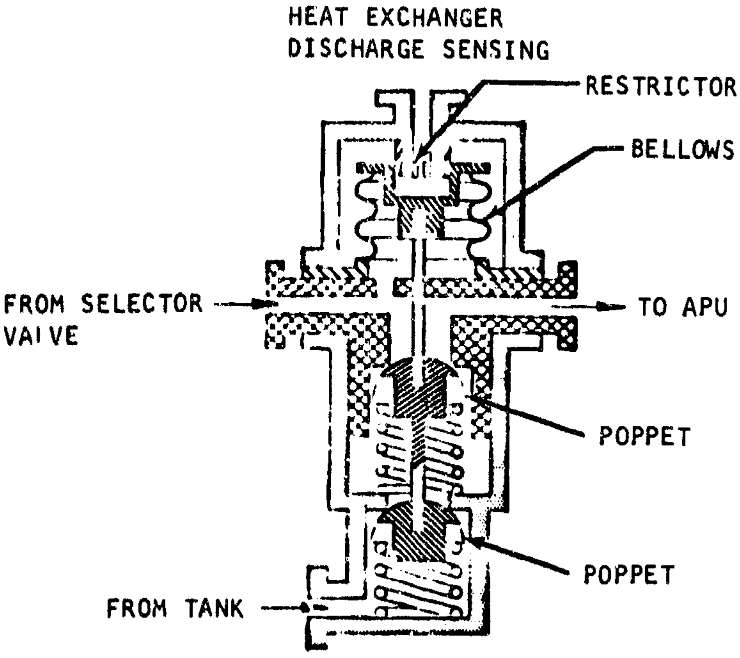
A functional schematic and a photograph of the valve are shown in Figure 71. The pressure drop across the entire control system (from heat exchanger outlet to APU supply line) is sensed by the bellows assembly. When this pressure differential exceeds 20 psi, the bellows strokes open the two poppet valves.

The restrictor in the heat exchanger discharge sensing line is a safety feature which limits hydrogen flow through the bellows in the event of a bellows failure.

The poppets are redundant in series against failure in the open position, with consequent loss of temperature control. If either poppet failed open, the remaining poppet would handle the normal function. If the bellows failed, the valve would remain closed.

7. Tank Pressurization Group

a. The Group As A Whole--The tank pressurization group maintains the hydrogen tank pressure at a preset level by returning some of the heat from the cooling load to the tank. The heat is obtained by tapping off a regulated amount of warm hydrogen from the discharge side of the glycol-to-hydrogen heat exchanger, and returning it to the mixing tee at the compressor inlet. The mechanism for doing this is illustrated schematically in Figure 72. As shown, the group consists of the absolute pressure regulator, the dual pressurization heat exchanger and fan, and the pneumatic relief valve. Heat is transferred from the warm hydrogen to cold tank hydrogen circulating through a loop outside the tank.



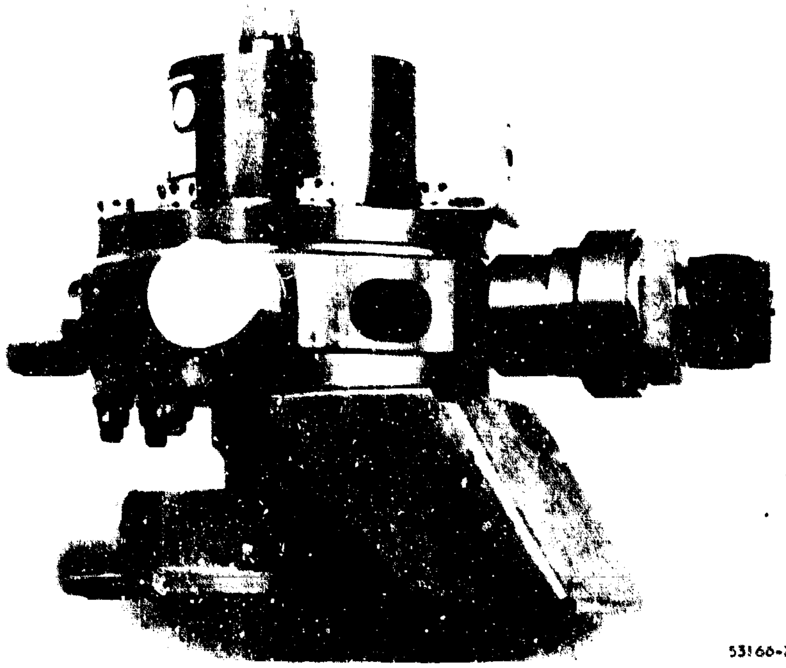


Figure 71. Differential Pressure Limiter Valve

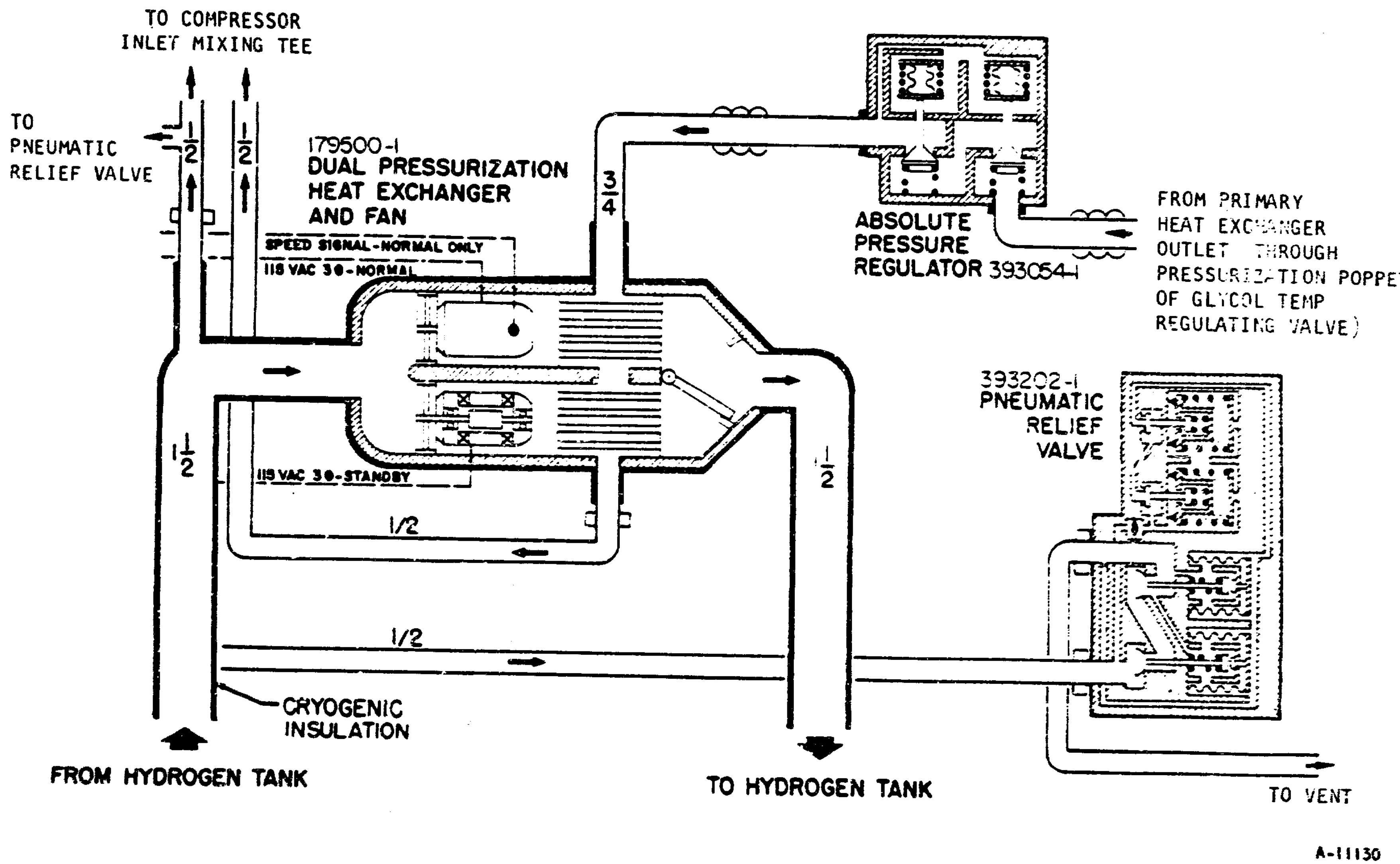


Figure 72. Tank Pressurization Group

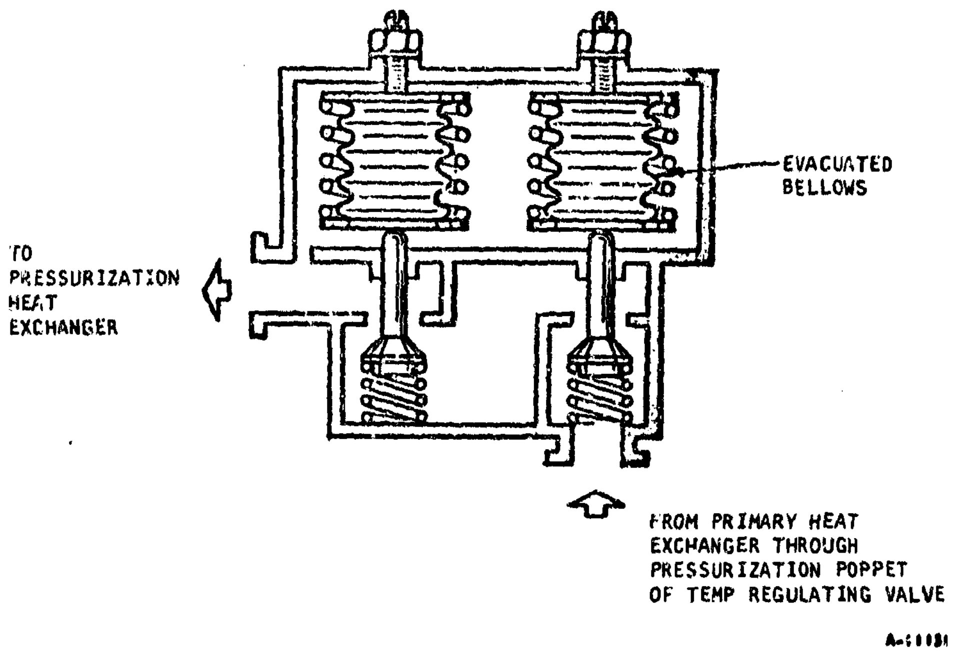


Figure 73. Absolute Pressure Regulator Schematic

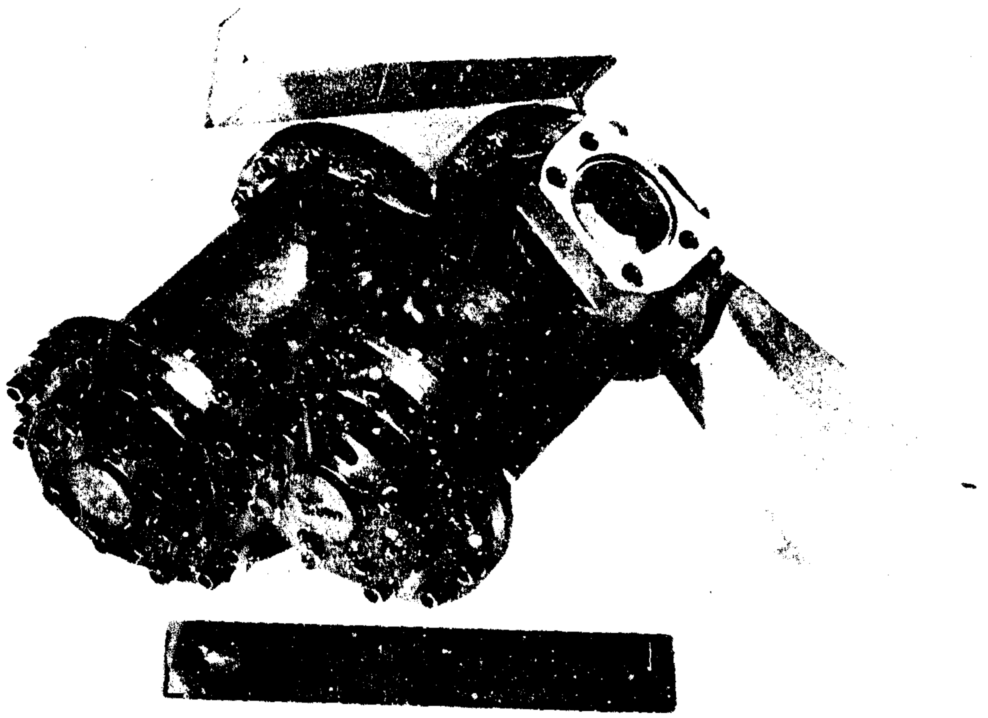


Figure 74. Absolute Pressure Regulator

b. Absolute Pressure Regulator--The absolute pressure regulator admits warm hydrogen to the pressurization heat exchanger as required to maintain the hydrogen tank pressure at a constant absolute level.

The operation is shown schematically in Figure 73 and a photograph of the unit is presented in Figure 74.

The evacuated bellows in the pressure regulator senses the tank pressure. When the tank pressure drops below the desired value, the spring opposing the pressure extends the bellows and opens the poppet valve. The action of the pressure on the bellows returns the valve to the closed position again when the tank pressure reaches the correct level. The two valves in series provide redundancy against the valve failing open as a result of a bellows failure.

c. Dual Pressurization Heat Exchanger and Fan--The heat exchanger transfers heat from the warm hydrogen to the cold supercritical hydrogen of the tank. The heat exchanger is located in a vacuum-jacketed loop outside the tank through which the tank hydrogen is continuously circulated by the pressurization fan.

The schematic arrangement of the unit is shown in Figure 75, and actual assembly details are shown in Figure 76. Photographs of the unit in various stages of assembly are shown in Figure 77.

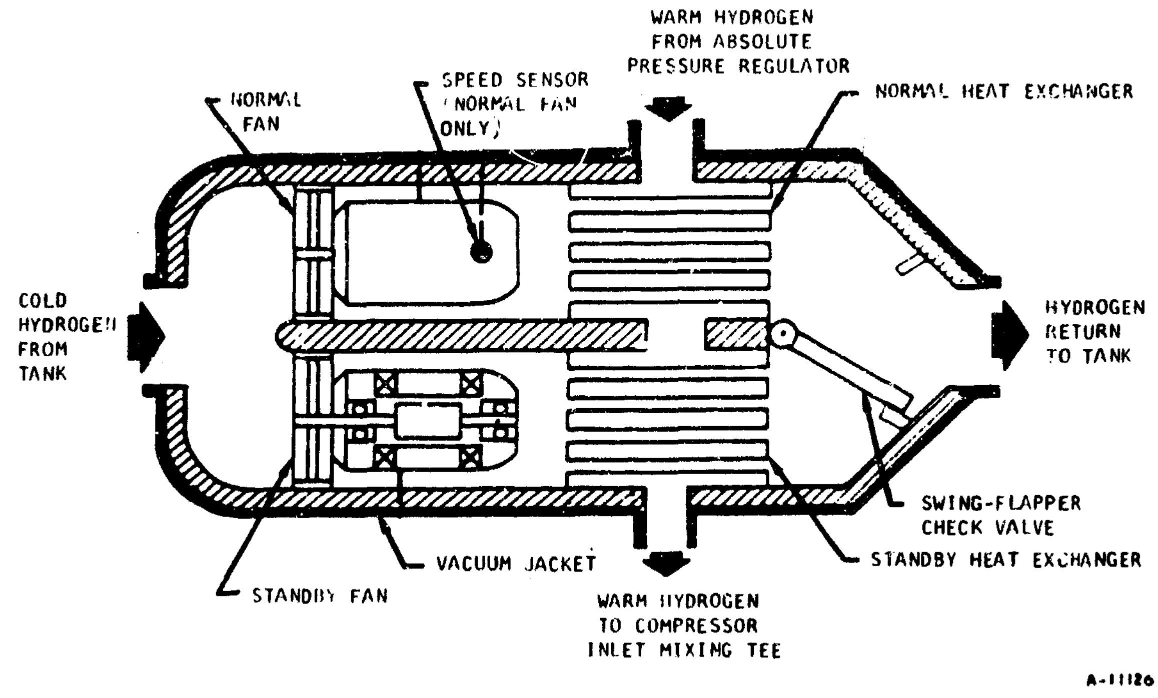


Figure 75. Dual Pressurization Heat Exchanger and Fan

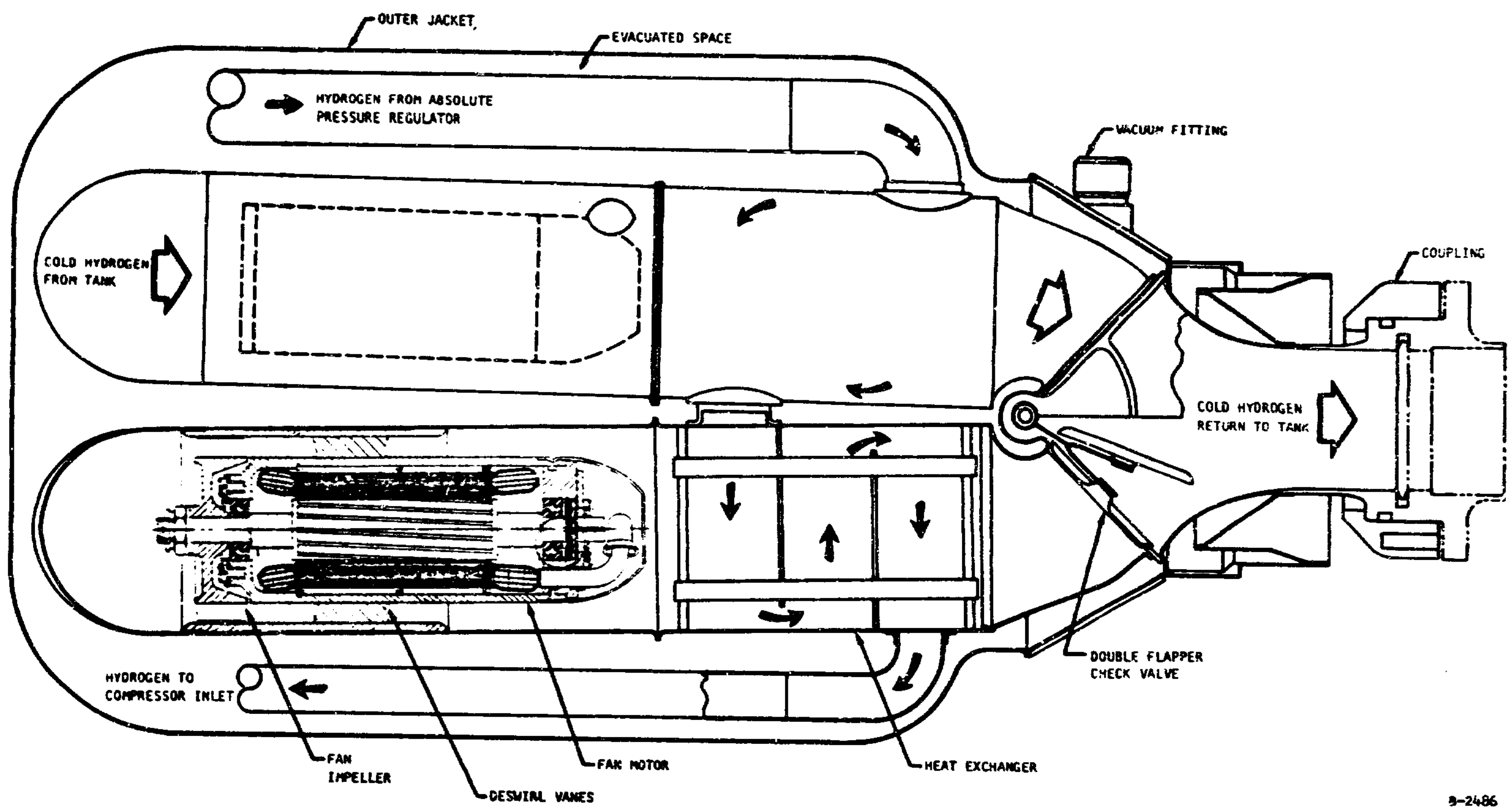
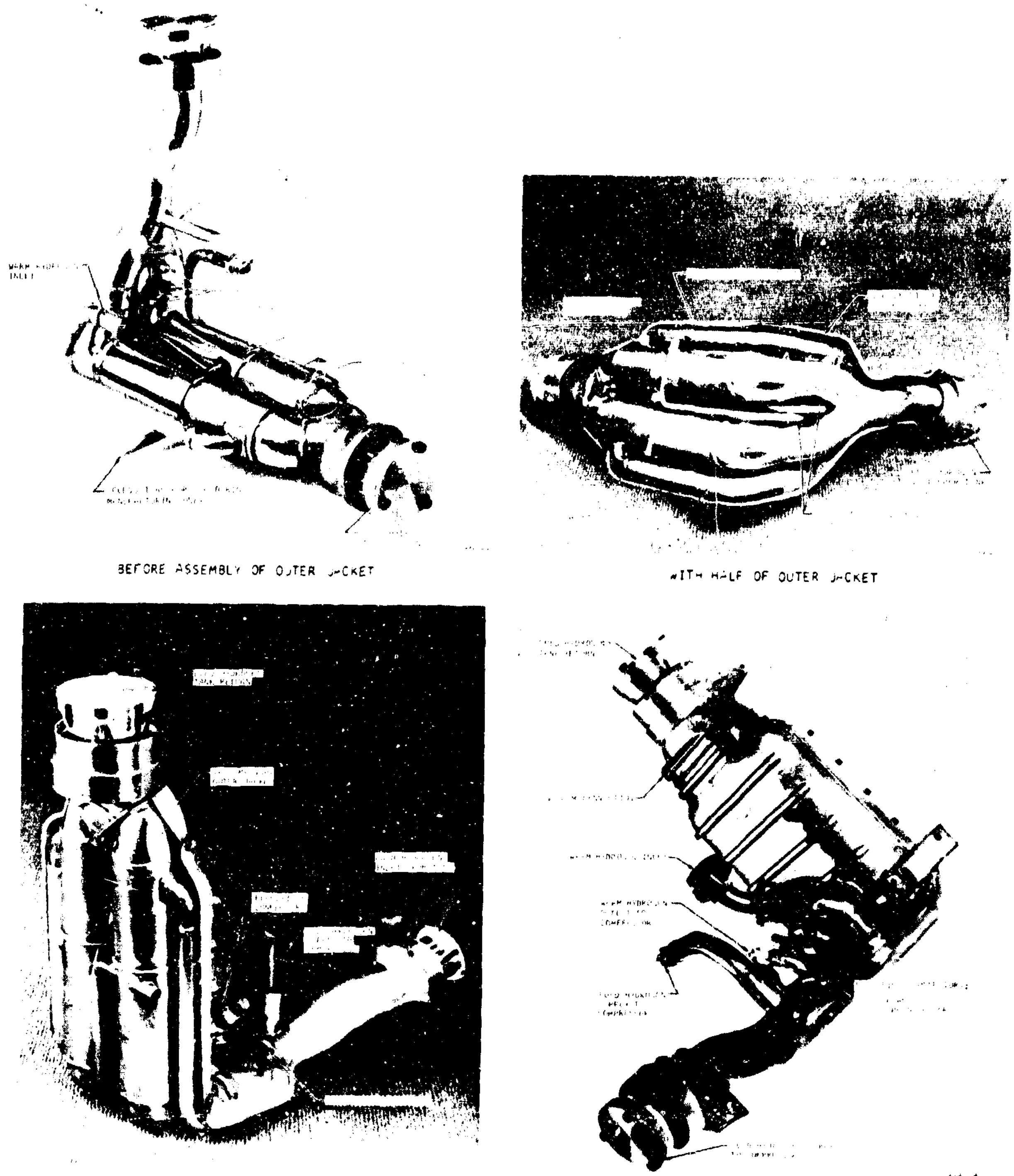


Figure 76. Details of Dual Pressurization Heat Exchanger and Fan



BEFORE ASSEMBLY OF OUTER JACKET

WITH HALF OF OUTER JACKET

BEFORE SEALING OF TUBE OPENINGS IN JACKET

COMPLETED UNIT

F-2160

Figure 77. Dual Pressurization Heat Exchanger and Fan

The two heat exchanger fan combinations in parallel are redundant against a fan failure. Only one fan is in operation at a time. The idle fan is isolated from the flow path by a swing-flapper check valve at the heat exchanger discharge.

The heat exchanger is of shell-and-tube construction, with cold hydrogen circulating continuously through the tubes, and warm hydrogen outside the tubes, flowing through both heat exchangers in series, in a three-pass cross-flow configuration.

The motor is a three-phase, six-pole induction motor which operates on 115/200-v, 400-cps a-c power.

The impeller is a single-stage unshrouded axial-flow impeller. The rotor is supported by stainless steel ball bearings with Rulon separators that obtain their lubrication and cooling from the hydrogen flow stream. The fan is shown in Figure 78.

The fan motor for normal-mode operation includes a speed sensor, which is monitored by the system selector package. When speed fails below an allowable limit, or if the normal power fails, the selector switches to the standby unit, which is connected to a standby-power source.

d. Pneumatic Relief Valve--The pneumatic relief valve provides a direct path from the tank to the vent when tank pressure exceeds a desired limit. To provide the necessary large flow area increase in a relatively narrow band of pressure increase ("popoff" action), the unit employs pilot, or servo, valves to actuate the main poppets. This arrangement is shown in Figure 79. This figure is schematic and not intended to indicate the physical arrangement of parts.

The exterior of the valve also is shown in Figure 80. The major components of this regulator are (1) two servo assemblies, each consisting of an evacuated bellows, a small poppet valve and a calibration spring, and (2) two actuator assemblies, each consisting of a larger poppet valve, a bellows, and several springs.

Tank pressure enters the chamber surrounding the evacuated bellows assemblies through a filtered flow passage. All four poppet valves remain closed when tank pressure is below the relief setting. When the tank pressure reaches the relief setting the servo bellows assemblies begin to compress, opening servo poppet No. 2 and then servo Poppet No. 1. The flow through these poppets passes through a fixed orifice, and the pressure around the actuator bellows assemblies increases causing them to compress and open the main poppet valves. The main actuator and servo poppets modulate as required to limit the maximum tank pressure.

The servo poppet cracking pressure can be changed by varying the evacuated bellows spring preload.

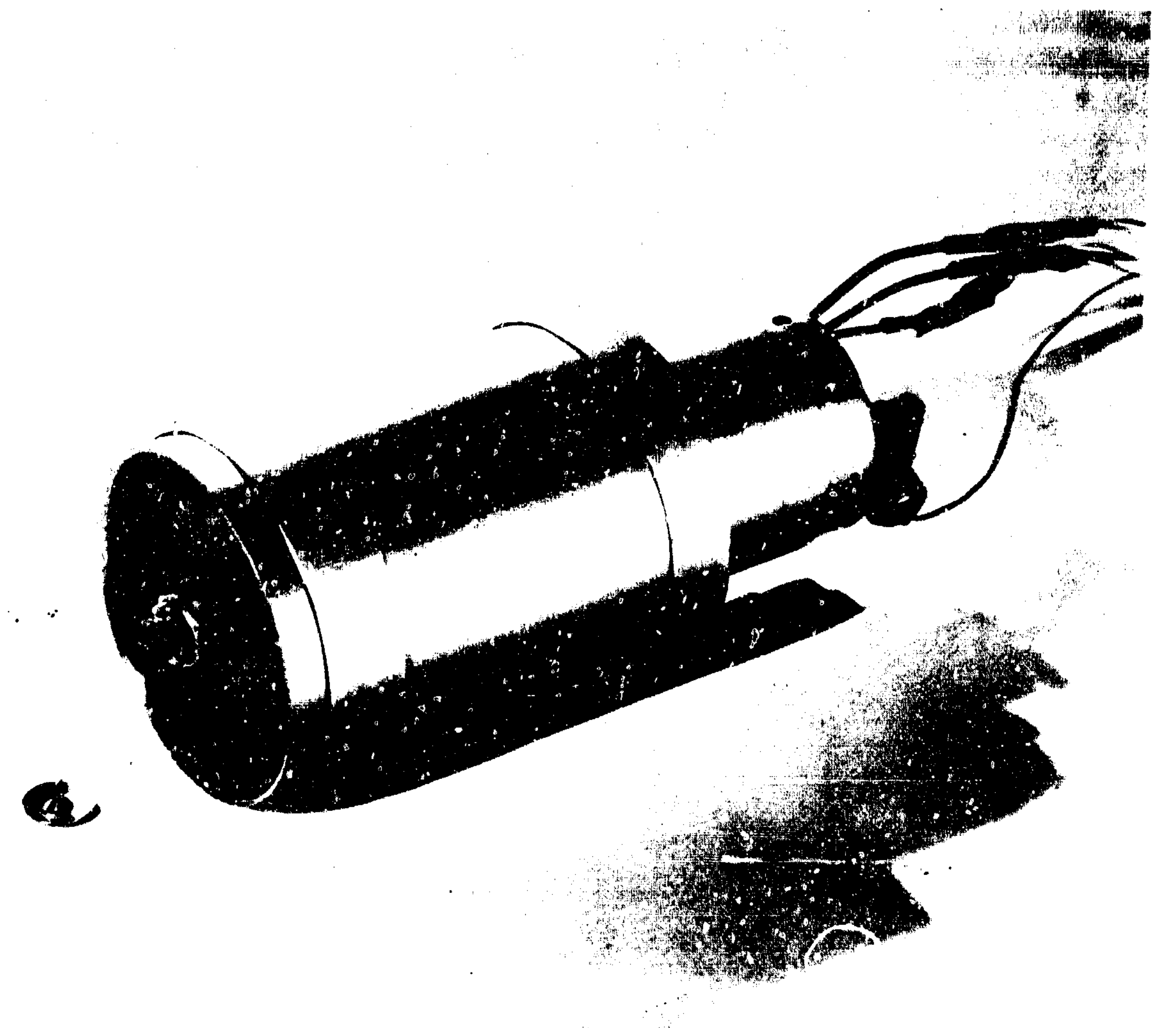


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Figure 78. Normal Pressurization Fan

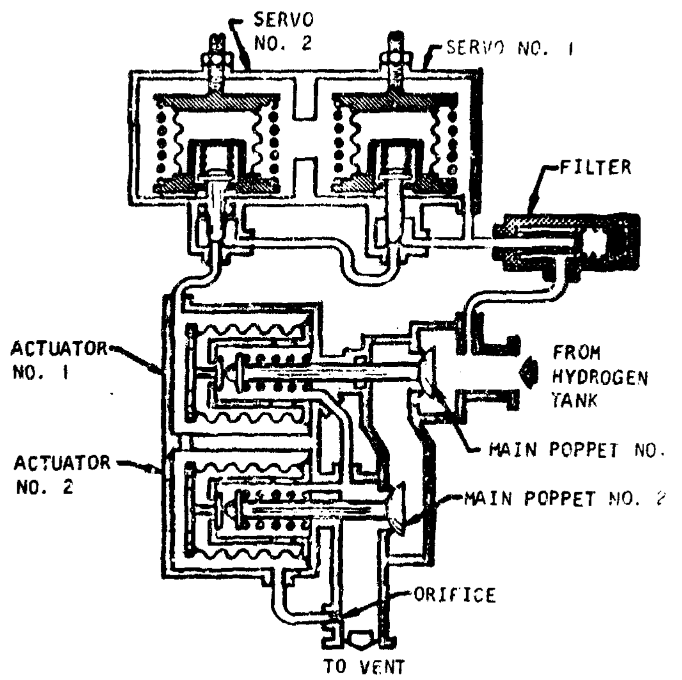
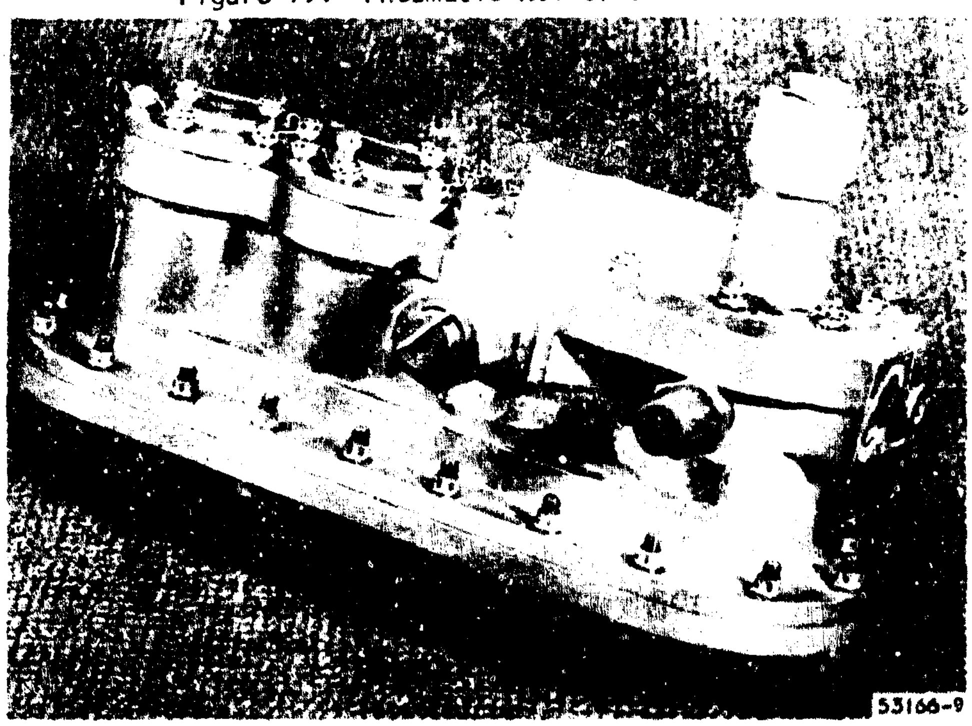


Figure 79. Pneumatic Relief Valve Schematic



F-2560

Figure 80. Pneumatic Relief Valve

The series redundancy is to decrease the probability of the relief valve failing open, as by a spring failure in either the servo or the main assemblies.

A single bellows failure could fail the unit closed, but this is considered less catastrophic than loss of hydrogen.

8. Glycol Temperature Sensor and Glycol Temperature Controller

The glycol temperature controller, together with the glycol temperature sensor, provide the servo signal that positions the glycol temperature regulating valve, thereby controlling the hydrogen throughflow through the glycol-to-hydrogen heat exchanger. The temperature sensor is shown in Figure 81. The temperature controller is shown in Figures 82 and 83; the former is a partially schematic block diagram.

The temperature sensor contains three platinum-wire temperature sensing elements located so that each senses the temperature of a common wall between the two glycol loops. The common wall is at the mean temperature of the two loops when both loops are flowing, and is very nearly at the temperature of the flowing loop if one loop fails.

One sensor serves the normal glycol temperature control circuit, the second is for the standby controller, and the third sensor detects out-of-tolerance glycol temperatures for the system selection controller. The system selection controller is described separately under its own heading.

Each sensing element is one leg of a two-leg bridge, which consists of a center-tapped transformer secondary, an externally adjustable rheostat, and the sensing element. This is illustrated schematically at the left in the block diagram. The temperature at which the bridge is balanced can be adjusted by means of the rheostat. The adjustment screws for the rheostats, R1, R2, and R3, are shown in the photograph of the sensor. The adjustments are set at AiResearch to obtain the following null temperatures:

Normal temperature control circuit	$10^{\circ}F$
Standby temperature control circuit	$15^{\circ}F$
Failure sensing circuit	$10^{\circ}F$

The failure sensing null point is the midpoint of the allowable temperature excursion band, from $-10^{\circ}F$ to $30^{\circ}F$. Outside this band, the system selector switches control from the normal to the standby circuits. This action is described separately under the glycol system selection controller.

In the temperature control circuit, a glycol temperature above or below the set point changes the resistance of the sensing element and unbalances the bridge. This results in a signal voltage (with respect to ground) at the output. Since the sensor input is an alternating voltage, the output is an

53166-3

Figure 81. Glycol Temperature Sensor

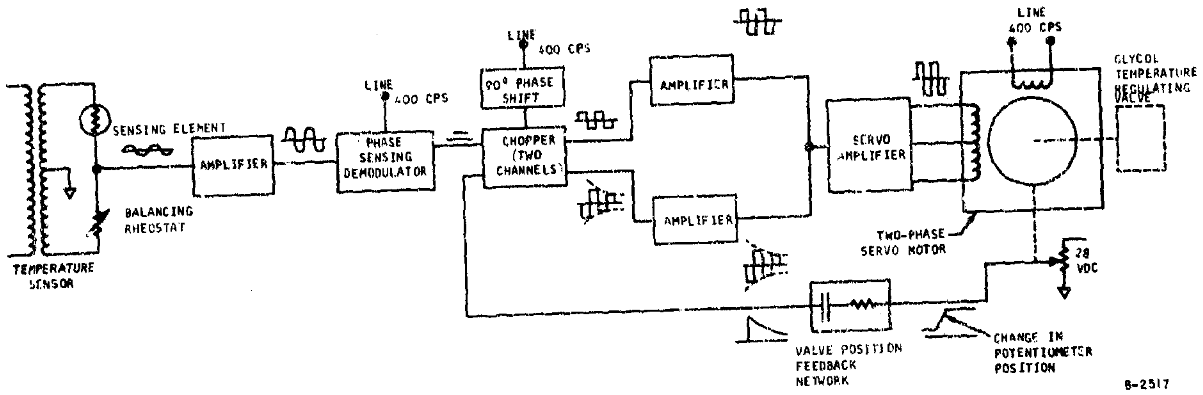
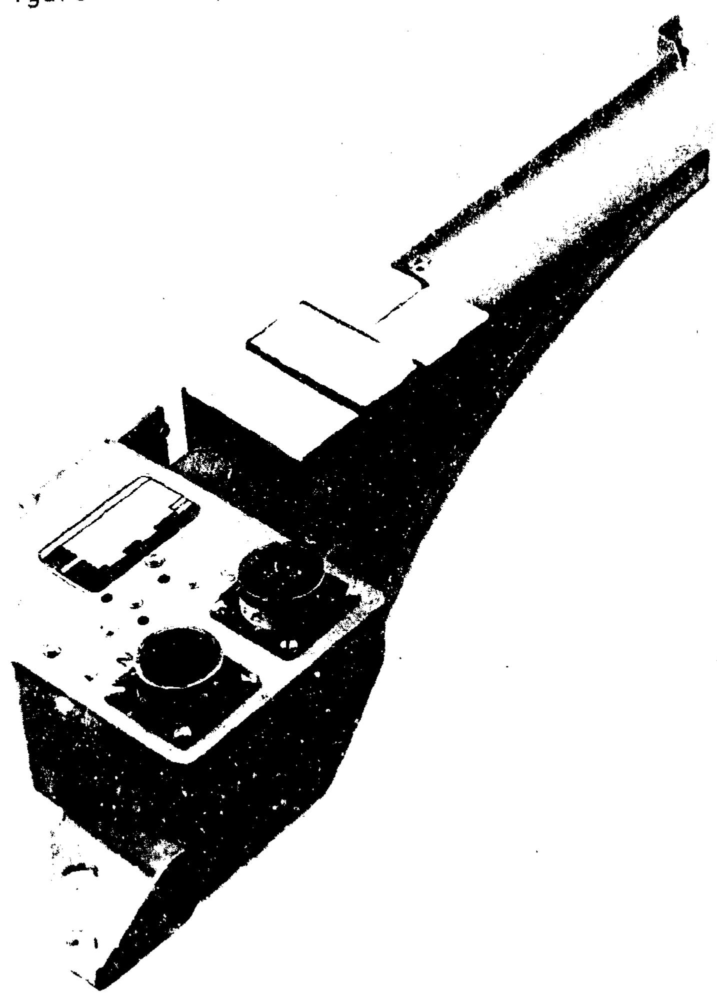


Figure 82. Glycol Temperature Controller Schematic



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F-2363

Figure 83. Glycol Temperature Controller

alternating voltage of magnitude proportional to the temperature error. The phase of an overtemperature error signal differs by 180 degrees from the phase of an undertemperature signal.

The error signal is amplified and applied to a phase-sensing demodulator, which compares the phase of the error signal with the line phase and delivers either a positive or a negative d-c signal, depending on the direction of the temperature error.

This d-c output of the demodulator supplies both the error signal and the rate signal. These d-c voltages are then combined algebraically and applied to the chopper, which creates a 400-cps square wave signal 90 degrees out of phase with line voltage, leading or lagging depending on the phase of the input signal and rate of change.

The amplified resultant square wave drives a servo amplifier, which supplies power to one of two windings of the temperature-regulating-valve actuator motor. The servocontrol voltage is 90 degrees out of phase with the line voltage. The direction of rotation is determined by whether the servocontrol voltage leads the line voltage by 90 degrees of lags by 90 degrees, the direction of phase shift being dependent on the resultant phase of the combined error, rate, and feedback signals.

To compensate for time lags of heat exchanger, valve, and other system elements, the error signal is modulated by negative feedback derived from motion of the valve. The feedback signal is generated by the combination of a voltage divider, or potentiometer, and capacitor which produce a signal that is a function of valve travel rate. The capacitor is in series with a resistor, giving the circuit a relatively large time constant, approximately 10 sec.

The feedback signal is converted by the chopper to a 400-cps square wave, 180 degrees out of phase with the error signal. The feedback square wave is amplified and applied to the error and rate signals ahead of the servoamplifier. Because of the opposite phase relationship of the error and feedback signal, the resultant signal reaching the servoamplifier is always reduced (damped) by the magnitude of the feedback.

This description has been made without discussion of the magnitude relationships of the error, rate, and feedback signals. The respective circuit gains furnished under the present contract are optimum, as determined from the analog computer studies and from the performance tests conducted on the -8 package with breadboard temperature controls immediately before cancellation of the original contract.

For simplicity, only the normal temperature regulating circuit has been described. The sensor and controller both include completely redundant circuits energized from separate power supplies. The redundant controls

function continuously during package operation so that, if switchover to standby occurs, the standby temperature regulating valve is already properly positioned. The standby sensor is nulled at 150°F, which is 5°F higher than the normal sensor. This ensures that the standby valve is always closed, thereby avoiding the possibility of switchover to an open valve and further cooling the glycol when the failure of the normal system may have been the result of too cold a glycol temperature. Failure of the normal system for high glycol temperature may result in some further temperature increase while the standby valve is traveling open, but this possibility is preferable to the possibility of subcooling.

9. Glycol System Selection Controller

The system selector, as this component is sometimes called in this report, actually has three separate circuits:

Valve group selector

Compressor speed discriminator

Fan speed discriminator

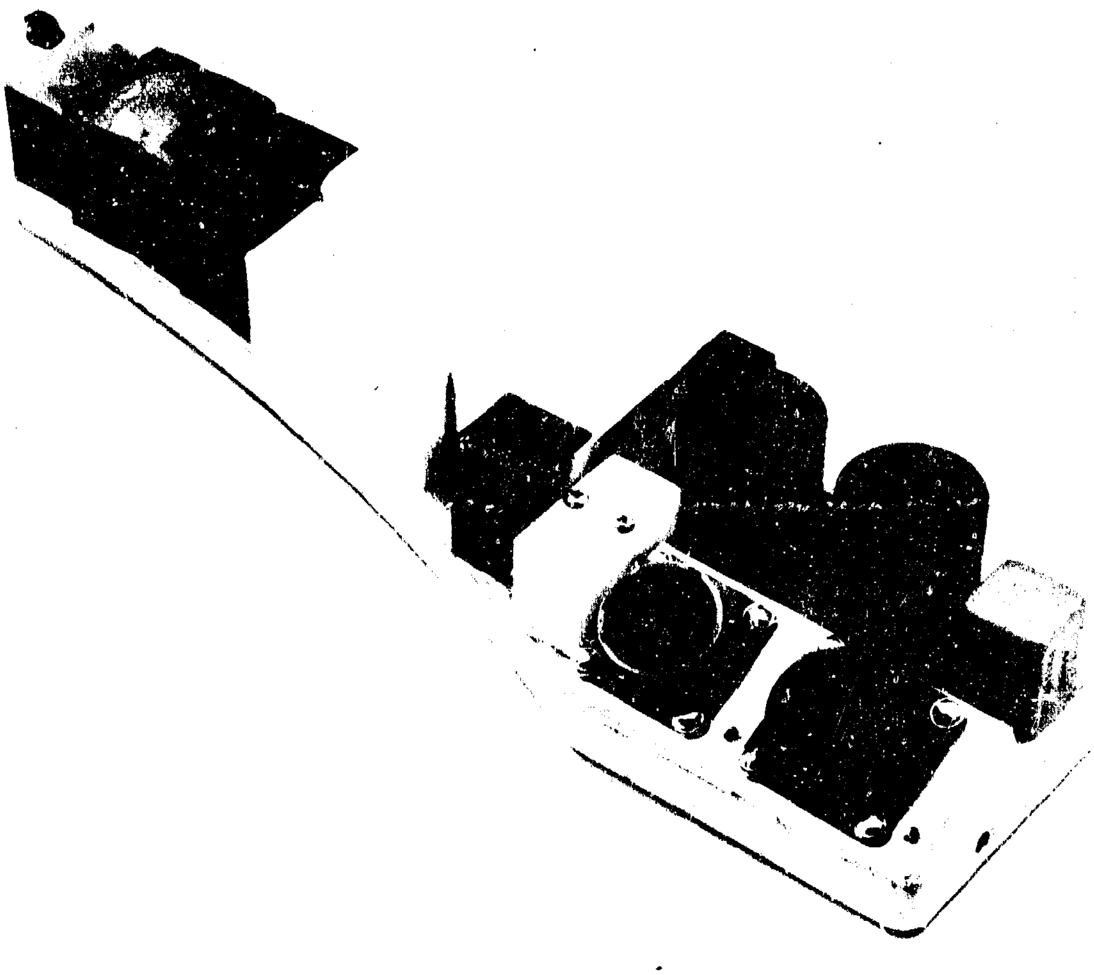
The system selector is shown in Figure 84. The valve group selector detects failure of the glycol temperature control system by monitoring glycol temperature at the primary heat exchanger outlet. When the glycol temperature exceeds 30°F or falls below -10°F, it activates the standby electropneumatic selector valve and deactivates the normal selector valve. The glycol temperature controller circuits themselves are both active continuously, hence are not turned on or off in the switching process.

The compressor and fan speed discriminators monitor the speed of these rotating machines, and switch them to standby operation, if speed falls below a predetermined trip speed.

a. Valve Group Selector--The function of the valve group selector is illustrated by the hybrid block diagram of Figure 85.

As shown in the diagram, the glycol temperature is sensed by a platinum-wire sensing element in a bridge circuit in the same manner as for the glycol temperature controller. Bridge unbalance produces an a-c signal, the amplitude being a direct function of the temperature excursion from the balanced, or null, temperature.

The signal is amplified and applied to a diode rectifier that is reverse-biased at a preset reference level. If the signal amplitude is less than the reference voltage, no signal appears at the silicon controlled rectifier (SCR). If the rectified a-c signal amplitude exceeds the reference voltage, the sine wave voltage peaks appear at the gate and act as firing voltage for the SCR.



53166-4

Figure 84. System Selector

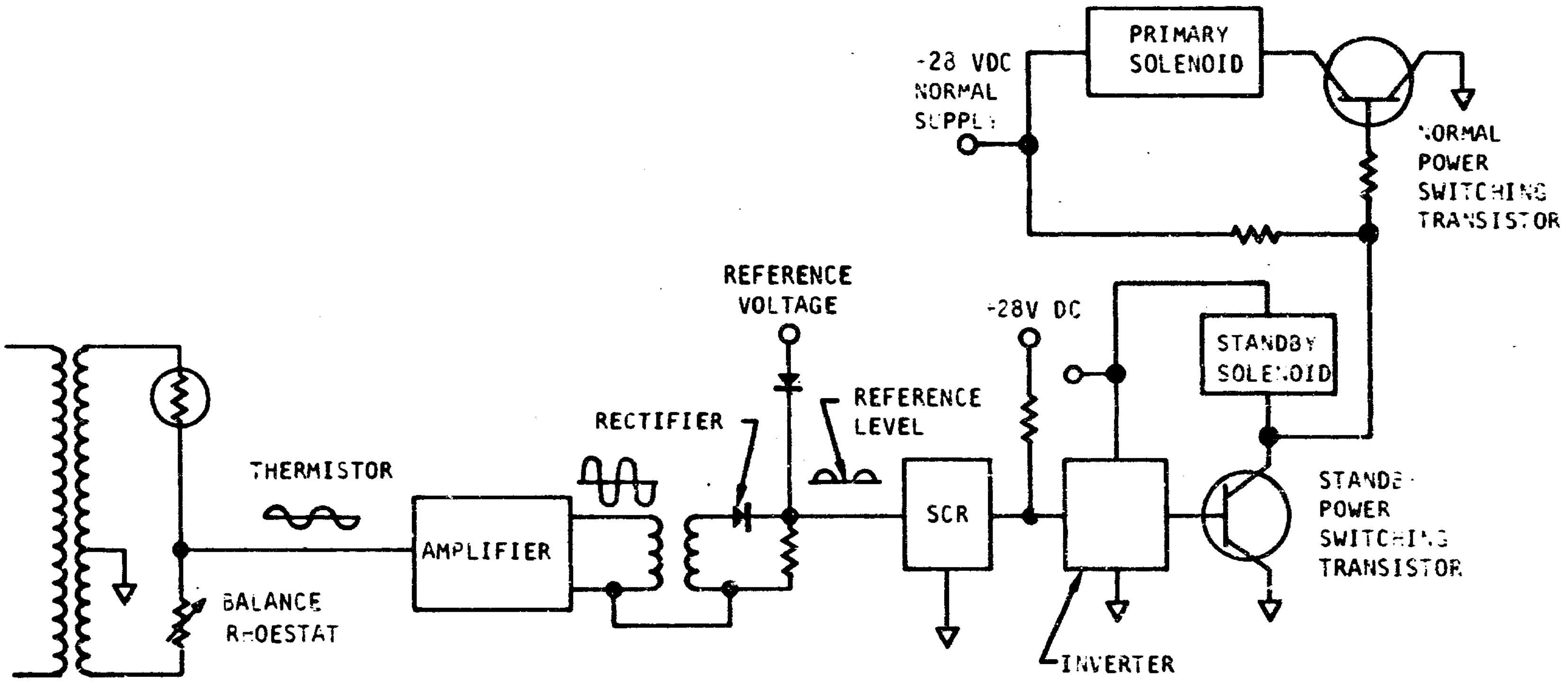


Figure 85. Valve Group Selector

When the SCR fires, the output of the SCR, or the input of the inverter, is low. Therefore, the output of the inverter is high and supplies current to the base of the standby switching transistor, causing it to turn on and to bring the collector to zero potential. This energizes the standby solenoid, and at the same time removes the base current from the normal power switching transistor, allowing it to go to the off state.

When the normal power fails, the normal valve immediately closes. This condition results in both valves being closed at the same time. The hydrogen flow stops and the glycol temperature rises. As soon as the temperature rises to the failure point of +30°F, the standby selector valve opens and hydrogen again begins to flow.

The switchover will occur for either overtemperature or undertemperature failure because, unlike the glycol temperature control circuit, its action depends only on magnitude of the temperature signal and not on phase of the signal.

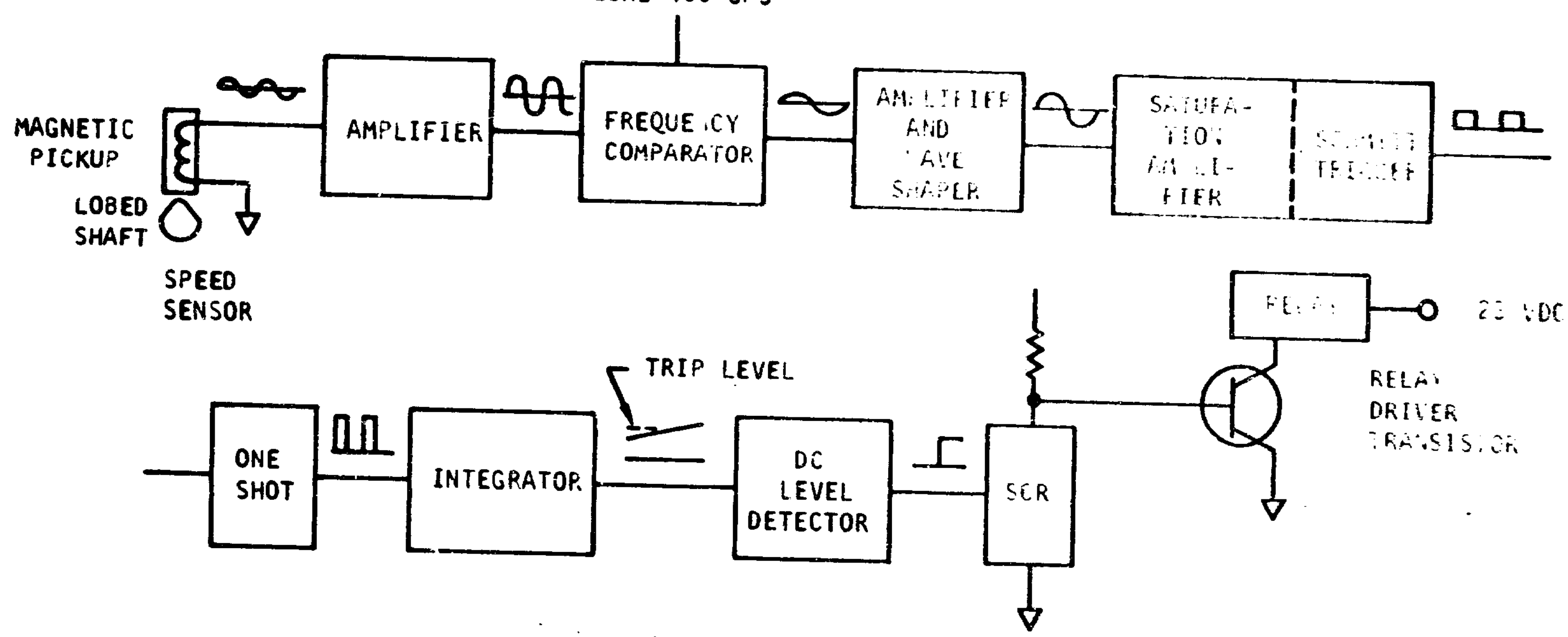
The SCR is bistable and will remain in the conducting mode until the supply current is removed. This essentially locks the system in standby operation until the power is interrupted.

b. Speed Discriminators--The normal recirculation compressor and the normal pressurization fan both have speed discriminators which monitor the shaft speeds. If the speeds fall below preset minimums, the discriminators switch off the normal units operating on normal power and switch on the standby units operating on the standby power. The two discriminators are very similar in operation.

Briefly, each discriminator compares the shaft speed with the line frequency, and provides a d-c voltage proportional to the difference in speed and line frequency, or "slip." If this d-c voltage should exceed a preset level, the holding voltage on a switching relay is removed, allowing the spring-loaded relay to switch to standby. The compressor discriminator trips at approximately 20,000 rpm (normal operating speed, 22,500 rpm). The fan discriminator trips at approximately 6450 rpm (normal operating speed, 7000 rpm).

The functional operation is described in the following paragraphs with the aid of the functional block diagram, Figure 86.

The speed of the shaft is sensed by a magnetic pickup located in close proximity to the shaft. The shaft is contoured, or lobed, in the vicinity of the magnetic pickup to present a varying magnetic reluctance to the pickups as the shaft turns. Each shaft generates an a-c signal as it rotates past the pickup. The compressor, operating at 22,500 rpm, has a speed near the 400-cps (24,000 cpm) power frequency, and therefore has only one lobe. The fan, which has an operating speed of 7000 rpm, needs four lobes to bring the speed sensor signal to a frequency conveniently close to power frequency for accurate comparison. Three lobes would have been used if the fan operated closer to synchronous speed, but, because of its high slip (13 percent compared to 6 percent for the compressor), a closer approach to power frequency at the



A-11152

Figure 86. Speed Discriminator

trip speed was obtained by four lobes. This results, however, in a speed signal frequency above the line frequency (about 470 cps operating, and 430 cps trip). This necessitates a slightly different failure detection technique, as described later.

The speed sensor signal is then amplified and compared to line frequency. The resultant output is at the "beat" frequency, which is equal to the difference between the applied speed signal and the line frequency. The beat signal is amplified and filtered to remove harmonics, and then applied to a stage of amplification which operates in the saturated mode.

As a result of operating in the saturated mode, the output from this stage has the waveform of a clipped sine wave. This signal is then used to drive a Schmitt trigger, which provides a square wave having the necessary rise time to fire the "one-shot" circuit. The one shot produces a pulse of specific width and amplitude each time the Schmitt trigger changes from the low to the high state. The repetition rate of the output pulses, therefore, is equal to the beat frequency.

The pulses are then integrated into a smooth d-c output. Since the width and amplitude of each pulse is uniform, the integrated d-c output level depends solely upon the pulse repetition rate. The magnitude of the output voltage is then proportional to the beat frequency. For the compressor, this voltage increases as the compressor speed decreases, because the operating speed signal frequency (about 375 cps) is below line frequency, and a decrease in compressor speed increases the line-to-speed signal frequency difference. For the fan, the opposite occurs. The fan operating speed signal (about 470 cps) is above line frequency, so a fan failure results in the speed signal frequency approaching line frequency.

The integrated d-c voltage is applied to a d-c level detector (a Schmitt trigger) which has no output until the input d-c voltage reaches a predetermined triggering level. For the compressor, the Schmitt trigger fires on increasing input voltage, while the Schmitt trigger in the fan speed discriminator circuit is made to fire on decreasing input voltage. This delivers, in each case, the necessary positive pulse to the SCR. The SCR, now made conductive, takes the current previously used to drive the relay driver transistor. The relay, now having the coil current removed, switches to the standby position.

The system will not remain in the standby mode of operation until the 28-v d-c power is interrupted.

In the case of a failure in the 28-v d-c standby power line, the relays will go to the standby position. Failure of the 28-V d-c normal power will have no effect on the speed discrimination.

Assembly and Operation

1. Operating Media

The glycol fluid to be used should be an aqueous ethylene glycol solution with inhibitors prepared as described for the -I unit.

The hydrogen is stored in the supercritical condition at 350 psia and delivered to the unit through short, vacuum-insulated pipes.

2. Fluid Connectors

The types and locations of the glycol connections and the hydrogen vent and APU connections are shown on Drawing SK 44514, submitted separately. The glycol fittings are designed to receive special double-seal Mil Flo fittings (as specified by the original contractor) and will not receive MS fittings without modification. They can be modified to receive MS fittings by grinding off the shoulder to make room for the MS hexagonal wrench flats.

The cryogenic couplings for connection to the hydrogen tank are a special double-seal design required by the original contractor. It is presumed that the package is to be operated in conjunction with the Dyna-Soar flight tank and that the mating couplings are already in existence. The package should be coupled to the tank as closely as possible to keep pressure drop in the recirculating cryogenic circuit as low as possible. The tank connecting lines should be compatible with the calculated pressure rise across the dual pressurization heat exchanger and fan of 0.24 in. H_2O $(\frac{\Delta P}{\delta})$, at 10 cfm, where ΔP is the overall pressure rise in in. H_2O and δ (delta) is the ratio of the hydrogen density to the density of standard air (0.0765 lb per cu ft). This pressure rise is based on the following:

Fan pressure rise $(\frac{\Delta P}{\delta})$ at 10 cfm	= 0.33 in. H_2O
Less heat exchanger and check valve	
pressure loss $(\frac{\Delta P}{\delta})$ at 10 cfm	= 0.09 in. H_2O
Net $\frac{\Delta P}{\delta}$	= 0.24 in. H_2O

3. Electrical Power

The package requires three types of electrical power:

a. 115/200-v, a-c, 3-phase, 400-cps, 4-wire

b. 115-v, a-c, single-phase

c. 28-v, d-c

In general, the three-phase power is required for the rotating machinery, the single-phase power is required for the electronics, and the d-c power is required for the electronics, relay switching, solenoid operation, and indicator lamps. The power distribution for all purposes is managed by the glycol temperature controller and the glycol system selector.

4. Electrical Connectors

The type and location of electrical connectors is shown on the Outline Drawing 179140. The power applied to these connectors is to be as follows:

Connector J1 (Normal System Selector)

Pin			
A	Phase A	115/200-v a-c, 3-phase, 400-cps	
B	Phase B		
C	Phase C		
D	Neutral		
E	28 v dc	Fan	switch to test
F	28 v dc	Compressor	
G	28 v dc	Temp Control Selector	
H	28 v dc		
J	Ground		
K			

Connector J21 (Normal Temperature Controller)

Pin		
A	28 v dc	
B	Ground	
C	115 v ac	Single-phase, 400-cps
D	Neutral	
E		
F		

Connector J2 (Standby System Selector)

Pin		
A	Phase A	115/200 v ac, 3-phase, 400 cps
B	Phase B	
C	Phase C	
D	Neutral	
E	28 v dc	Interruption of this voltage will cause reset to normal operation
F	Ground	
G	115 v ac	Single-phase, 400-cps
H	Neutral	
J	28 v dc, standby selector valve indicator light, 50 ma	
K	28 v dc, standby fan and compressor indicator light, 50 ma	

Connector J20 (Standby Temperature Controller)

Pin		
A	28 v dc	
B	Ground	
C	115 v ac	Single-phase, 400-cycle
D	Neutral	

5. Starting Procedure

This starting procedure is written as if the -8 package were connected to the complete thermal management system. It applies also to simulated glycol loops if reference to specific Dyna-Soar units are disregarded. The philosophy on which the procedure is based is summed up in the following vital precautions:

a. Avoid a combustible hydrogen-oxygen mixture in the vicinity of personnel or equipment.

b. Eliminate gases and vapors which would condense or freeze when the system is filled with cryogenic hydrogen.

c. Do not start the dual recirculation compressor or the pressurization fan until they are immersed in cold hydrogen.

d. Remove all air from the glycol loops, to avoid pump cavitation and heat exchanger blockage.

The basic steps during start-ups are as follows:

a. Ensure that there are no leaks. The hydrogen circuits should be tested with an inert gas, such as nitrogen.

b. Evacuate the glycol loops to 100 microns Hg abs or less.

c. Isolate the vacuum source and admit glycol to both loops. The glycol may be at ambient temperature and pressure.

d. Start the glycol pumps and circulate the glycol. During this step, the loops should be routed through a reservoir or tank having a fill-liquid surface to enable trapped air to separate. This dearating tank can be pressurized to control system pressure.

e. Cycle the accumulators through their full travel five times to purge air from the accumulators. This cycling can be accomplished by varying the pump inlet pressure from some convenient value below 6 psig to that pressure (about 18 psig) required to fill the accumulators.

f. Adjust system pressure (at the pump inlet) to 12 ±1 psig in each loop and close off the external reservoir.

g. Start the -1 and -3 cooling unit fans.

h. Evacuate the hydrogen system to the lowest pressure obtainable with practical equipment. The absolute pressure should be lower than 0.5 in. Hg abs. The hydrogen system includes the run tank and the APU and vent lines. The length of APU and vent lines to be evacuated will depend on the individual setup, local safety regulations, whether or not an APU is actually being used, etc.

Because the selector valves in the -8 package are closed, it will be necessary to connect the vacuum source to the APU and vent lines as well as to the tank end of the circuit.

i. Isolate the vacuum source and charge the hydrogen circuit with dry nitrogen to a slight positive pressure.

j. Evacuate and charge the system with dry nitrogen at least three times.

k. Then evacuate and charge the system with room-temperature hydrogen at least twice.

l. Disconnect the vacuum source and the gas charging lines.

m. Fill and top-off the tank with subcooled, liquid hydrogen.

n. Allow the tank pressure to build up to 320 psig to bring the hydrogen to the supercritical state. This process may be accelerated by internal heaters or by pressurizing with hydrogen gas.

o. Apply power to all electrical circuits of the -8 package. This will start the rotating machinery and open the normal or standby selector valve, depending on the glycol temperature being sensed.

p. Apply a heat load of 400 to 980 Btu per min to each glycol loop.

q. If the system selector switches to the standby control mode, the control can be returned to normal by briefly interrupting the 28-v d-c power.

r. Hydrogen may now be withdrawn from the APU supply line for simulated or actual APU operation. The hydrogen supplied to the line by the package may be cryogenic, depending on the glycol cooling load and the amount of APU hydrogen withdrawn; therefore provision should be made for the APU to accept cryogenic hydrogen.

6. Shutdown Procedure

a. Remove the heat loads, except for a small token heat load as afforded by the cold plates and the APU and gererators. Leave the -1 and -3 fans running.

b. When the heat sources have cooled, shut down the -8 package, then the pumps, and then the -1 and -3 cooling units. Removing the power from the -8 package will close the selector valves and stop the hydrogen flow through the control valves. If the APU has not been shut down, hydrogen will be supplied through the completely pneumatic differential pressure limiter, with

tank pressure diminishing. When the APU is shut down, the residual hydrogen in the tank will vent through the pressure relief valve as a result of the ambient heat leak into the tank.

7. Auxiliary Pressure Relief

It is recommended that a tank pressure relief valve be included on the hydrogen test tank, so that sole reliance on the relief valve in the -8 package will not be necessary. Although the -8 relief valve had redundant poppets and actuators, the poppets are redundant in series (against a failed-open poppet, as resulting from a ruptured bellows), and a failure of one poppet in the closed position would fail the pressure-relief function.

8. Handling

The -8 package must be handled with care. The compressor and fan bearings are not lubricated and must be kept free from shock and vibration while not operating, otherwise small Brinell and fret marks could seriously reduce bearing life.

Performance

1 Design Requirements

The performance of the -8 package is summarized in the following design requirements.

Applied Conditions

Maximum cooling loads

Loop 1		980 Btu per min
Loop 2		980 Btu per min

Normal minimum cooling loads

Loop 1		401 Btu per min
Loop 2		344 Btu per min

Minimum cooling loads under failure conditions

Failure of either -1 or -3 package

Failed loop		240 Btu per min
Operating loop	(Loop 1)	365 Btu per min
	(Loop 2)	310 Btu per min

Failure of either the APU alternator or -4 package

Failed loop		60 Btu per min
Operating loop	(Loop 1)	365 Btu per min
	(Loop 2)	310 Btu per min

Glycol flow	5.43 lb per min

a. Glycol Outlet Temperature--The glycol outlet temperature from each loop is maintained at 10 ±5°F in the normal mode and 15 ±5°F in the standby mode. Glycol temperature will stabilize within the control within 5 minutes after either of the following:

Complete or partial loss of one of the glycol loops so that the cooling loads are those listed under failure conditions in "applied conditions."

Restart of the APU following loss of electrical power.

The glycol temperature will remain within the control band during and after the following transients:

Normal heat load changes resulting from combined normal changes for -1, -3, and -4 packages.

APU hydrogen flow demands

Hydrogen flows required to provide the thermal energy return for tank pressurization provided that sufficient heat is available.

b. Tank Pressurization--Provided that sufficient heat is available, the -8 package returns sufficient heat to the tank pressurization circuit to maintain the tank pressure above 320 psia. The package recirculates cryogenic hydrogen to and from the tank at 10 cfm for hydrogen densities from 0.5 to 4.6 lb per cu ft.

c. Hydrogen Pressure Drop--The hydrogen pressure drop across the -8 package at a hydrogen flow to the APU of 3.6 lb per min does not exceed 21 psi for all densities between 4.6 and 0.5 lb per cu ft. Under loss of electrical power or loss of glycol cooling, the pressure drop does not exceed 25 psi for the same flow and density range.

d. Pressure Relief--The pressure-relief cracking pressure is 375 ±10 psi, with a full flow of 9.0 lb per min at 385 psia or less.

e. Venting--Hydrogen is not vented overboard when the APU demand is in excess of the cooling demand.

f. APU Hydrogen Supply Pressure--The package maintains pressure at the APU supply port of 300 psia or greater.

g. Electrical Power Consumption--The electrical power consumption shall not exceed:

A-C power - 285 w

D-C power - 57 w

The fluid passages have been designed to withstand the following pressures:

	Maximum Operating, psig	Proof, psig	Burst, psig
Glycol	110	165	275
Hydrogen	350	525	875

h. Weight--The weights of the package in the two frame configurations are:

	Dry, lb	Wet, lb
Original frame (calculated)	120 29	125.29
Expanded frame (actual)	120.25	125.25 (estimated)

More detailed performance of the heat exchangers and rotating machinery is presented in the following paragraphs.

2. Primary Heat Exchanger Performance

Gaseous normal hydrogen was used in the test instead of parahydrogen, but heat exchanger thermal conductance should not be different. Although the enthalpies of the two gas states may differ, their heat transfer properties appear to be the same.

The unit tested is representative of the current production unit with the exception that the production unit contains approximately 25 percent more heat transfer surface in the cross-parallel section Also, the test unit had two hydrogen manifolds between sections which are not used in the production configuration. Therefore, the production unit should have higher thermal conductance and lower hydrogen pressure drop than the test unit.

A summary of heat transfer data recorded is presented in Tables 3 and 4. Representative pressure drop data are plotted in Figures 87 and 88, and overall thermal conductance is shown in Figures 89 and 90. On the pressure drop curves there is a third test specimen shown, PA-54081-1A, which was a special test section without turning pans. This configuration was not developed further because of a severe increase in pressure drop and loss of heat rejection when the wall temperature approached the glycol congealing temperature.

TABLE 3

THERMAL CONDUCTANCE TESTS - CROSS-COUNTERFLOW UNIT

I CONSTANT: HYDROGEN FLOW, 1.05 ± .01 LB/MIN; INLET TEMPERATURE, 460 ± 2 °R; GLYCOL-WATER INLET TEMPERATURE, 120 ± 2 °F.

RUN NO.	GLYCOL-WATER FLOW LBS/MIN.	HEAD GLYCOL-WATER TEMP. °F	GLYCOL-WATER PRESSURE DROP PSI	Q_{TOTAL} BTU/MIN.	UA BTU/MIN.°R	ϵ_{H_2}
2105	4.22 & 4.22	81.3 & 81.6	4.41 & 4.43	414	18.3	.944
2106	4.20 & 4.20	86.1 & 86.4	4.61 & 4.65	418	18.2	.939
2103	4.80 & 4.82	90.1 & 90.6	4.95 & 5.4[illegible]	420	19.6	.952
2104	4.80 & 4.81	90.2 & 90.[illegible]	4.96 & 5.00	422	18.5	.986
2101	5.49 & 5.39	92.8 & 93.1	5.59 & 5.65	431	18.3	.961
2102	5.43 & 5.39	93.3 & 92.4	5.51 & 5.53	428	18.1	.960
2107	6.02 & 6.06	95.9 & 96.3	6.36 & 6.36	434	19.4	.979
2108	6.02 & 6.04	96.6 & 96.9	6.26 & 6.29	420	18.6	.959
2109	6.57 & 6.61	97.2 & 98.1	6.92 & 7.06	441	21.4	.981
2110	6.57 & 6.61	96.4 & 96.7	6.91 & 7.05	433	20.7	.980

II CONSTANT: HYDROGEN FLOW, 1.65 ± .01 LB/MIN., INLET TEMPERATURE, 460 ± 2 °R; GLYCOL-WATER INLET TEMPERATURE, 120 ± 2 °F

2610	4.20 & 4.21	71.5 & 74.7	7.71 & 7.90	575	22.4	.801
2611	4.20 & 4.21	72.4 & 71.3	7.68 & 7.87	576	23.9	.803
2608	4.80 & 4.83	76.3 & 77.3	7.71 & 7.4[illegible]	618	23.3	.839
2609	4.80 & 4.83	75.6 & 77.1	7.77 & 7.92	614	23.9	.843
2605	5.43 & 5.43	80.5 & 80.9	7.40 & 7.51	620	23.7	.877
2606	5.43 & 5.43	81.4 & 80.6	7.39 & 7.51	615	23.1	.876
2603	6.07 & 6.06	84.5 & 84.6	7.94 & 8.0[illegible]	625	23.4	.896
2604	6.05 & 6.05	84.2 & 84.3	7.95 & 8.05	627	23.4	.897
2601	6.60 & 6.60	86.7 & 87.0	8.27 & 8.50	633	23.9	.911
2602	6.60 & 6.57	86.7 & 87.0	8.32 & 8.46	624	23.6	.916

III CONSTANT: HYDROGEN FLOW, 2.07 ± .02 LB/MIN.; INLET TEMPERATURE, 460 ± 1 °R; GLYCOL-WATER INLET TEMPERATURE, 119 ± 1 °F.

2701	4.20 & 4.21	67.2 & 67.6	10.09 & 10.30	625	24.5	.696
2702	4.21 & 4.21	67.4 & 67.3	10.06 & 10.18	627	24.9	.700
2703	4.80 & 4.80	71.6 & 71.6	9.45 & 9.66	672	25.3	.748
2704	4.80 & 4.80	70.1 & 70.4	9.57 & 9.75	665	26.1	.747
2705	5.41 & 5.41	74.2 & 74.8	9.35 & 9.55	706	25.4	.786
2706	5.41 & 5.43	74.6 & 74.9	9.36 & 9.5[illegible]	704	25.2	.785
2707	6.05 & 6.05	78.4 & 78.9	9.62 & 9.72	724	24.9	.815
2708	6.05 & 6.06	78.4 & 78.3	9.51 & 9.67	723	24.2	.818
2709	6.60 & 6.60	80.4 & 80.5	9.85 & 9.94	738	25.6	.845
2710	6.60 & 6.60	80.4 & 80.5	9.84 & 9.96	742	25.3	.843

IV CONSTANT: HYDROGEN FLOW, 1.06 $^{+.01}_{-.02}$ LB/MIN.; INLET TEMPERATURE, 425 $^{+1}_{-2}$ °R, GLYCOL-WATER INLET TEMPERATURE, 240 ± 3 °F.

RUN NO.	GLYCOL-WATER FLOW LBS/MIN.	HEAD GLYCOL-WATER TEMP. °F	GLYCOL-WATER PRESSURE DROP PSI	Q_{TOTAL} BTU/MIN.	UA BTU/MIN.°R	ϵ_{H_2}
2001	4.22 & 4.17	166 & 166	2.10 & 2.14	961	18.8	.950
2002	4.18 & 4.19	168 & 167	2.19 & 2.1[illegible]	986	19.2	.940
2003	4.79 & 4.84	178 & 178	2.32 & 2.3[illegible]	969	19.2	.989
2004	4.80 & 4.84	178 & 178	2.30 & 2.3[illegible]	970	18.9	.965
2005	5.44 & 5.45	183 & 180	2.75 & 2.79	999	20.1	.964
2006	5.47 & 5.50	182 & 182	2.80 & 2.[illegible]	995	19.1	.969
2007	6.03 & 6.05	186 & 187	3.13 & 3.13	982	19.1	.975
2008	6.05 & 6.07	187 & 187	3.14 & 3.13	991	20.0	.977
2009	6.59 & 6.60	192 & 192	3.46 & 3.4[illegible]	1001	19.9	.990
2010	6.58 & 6.57	192 & 193	3.41 & 3.41	999	19.4	.979

V CONSTANT: HYDROGEN FLOW, 1.66 $^{+.02}_{-.01}$ LB/MIN., INLET TEMPERATURE, 425 $^{+1}_{-2}$ °R; GLYCOL-WATER INLET TEMPERATURE, 240 ± 2 °F.

2209	4.22 & 4.18	136 & 138	4.39 & 4.33	1347	22.7	.815
2210	4.20 & 4.18	135 & 137	4.35 & 4.38	1338	23.6	.831
2207	4.82 & 4.86	140 & 147	3.76 & 3.67	1382	23.1	.869
2208	4.85 & 4.82	147 & 148	3.89 & 3.92	1394	23.4	.861
2205	5.48 & 5.48	156 & 158	3.80 & 3.97	1442	23.5	.890
2206	5.46 & 5.46	156 & 159	3.76 & 3.81	1417	23.5	.892
2203	6.11 & 6.08	165 & 163	3.96 & 4.02	1465	23.5	.911
2204	6.06 & 6.07	163 & 169	4.00 & 4.04	1464	23.6	.907
2201	6.60 & 6.60	170 & 172	4.10 & 4.16	1473	23.7	.920
2202	6.60 & 6.60	169 & 170	4.10 & 4.16	1482	23.6	.915

VI CONSTANT: HYDROGEN FLOW, 2.06 ± .04 LB/MIN.; INLET TEMPERATURE, 425 $^{+3}_{-3}$ °R; GLYCOL-WATER INLET TEMPERATURE, 240 $^{+3}_{-5}$ °F.

2301	4.22 & 4.20	123 & 123	7.71 & 7.49	1804	28.9	.726
2302	4.22 & 4.20	123 & 124	7.25 & 7.37	1481	28.8	.732
2303	4.81 & 4.86	135 & 136	5.42 & 5.41	1567	24.1	.784
2304	4.85 & 4.86	133 & 130	5.87 & 6.00	1559	26.3	.786
2305	5.43 & 5.39	143 & 143	4.19 & 4.91	1632	23.9	.795
2306	5.42 & 5.40	140 & 143	4.97 & 5.01	1622	25.1	.814
2307	6.06 & 6.06	151 & 154	4.68 & 4.75	1627	24.9	.850
2308	6.06 & 6.06	148 & 149	4.96 & 4.89	1662	24.3	.832
2309	6.55 & 6.58	156 & 157	4.80 & 4.90	1722	24.9	.852
2310	6.55 & 6.58	157 & 156	4.85 & 4.91	1700	24.7	.864

TABLE 4

THERMAL CONDUCTANCE TESTS - CROSS-PARALLEL FLOW UNIT

I CONSTANT: HYDROGEN FLOW, 1.05 ± .01 LB/MIN; INLET TEMPERATURE, 435 ± 2°R; GLYCOL-WATER INLET TEMPERATURE, 40 ± 1 °F.

RUN NO.	GLYCOL-WATER FLOW LBS/MIN.	MEAN GLYCOL-WATER TEMP °F	GLYCOL-WATER PRESSURE DROP PSI	Q_{TOTAL} BTU/MIN.	UA BTU/MIN.°R	ϵ
1611	4.22 & 4.20	27.7 & 28.2	6.46 & 6.35	136	3.81	.621
1612	4.22 & 4.20	27.5 & 27.4	6.41 & 6.34	138	3.83	.519
1601	4.80 & 4.80	28.5 & 28.7	6.61 & 6.61	136	3.76	.512
1602	4.80 & 4.80	28.4 & 28.3	6.72 & 6.61	139	3.82	.541
1605	5.41 & 5.50	30.1 & 30.0	7.81 & 7.86	146	3.88	.545
1606	5.42 & 5.43	28.5 & 29.2	7.87 & 7.01	149	3.83	.558
1607	6.05 & 6.05	31.1 & 31.3	8.45 & 8.45	146	3.84	.560
1608	6.05 & 6.05	31.1 & 31.2	8.34 & 8.24	145	3.86	.567
1609	6.60 & 6.61	31.6 & 31.8	8.82 & 8.73	142	3.76	.511
1610	6.60 & 6.61	31.4 & 32.1	8.85 & 8.80	146	3.80	.570

II CONSTANT: HYDROGEN FLOW, 1.60 ± .02 LB/MIN, INLET TEMPERATURE, 428 ± 1½ °R; GLYCOL-WATER INLET TEMPERATURE, 40 ± 1½ °F.

RUN NO.	GLYCOL-WATER FLOW LBS/MIN.	MEAN GLYCOL-WATER TEMP °F	GLYCOL-WATER PRESSURE DROP PSI	Q_{TOTAL} BTU/MIN.	UA BTU/MIN.°R	ϵ
1803	4.23 & 4.22	26.1 & 26.2	6.76 & 6.76	167	4.30	.398
1804	4.23 & 4.22	26.2 & 26.4	6.76 & 6.76	167	4.35	.405
1201	4.82 & 4.80	26.6 & 27.1	7.52 & 7.56	172	4.46	.420
1202	4.82 & 4.80	26.5 & 26.4	7.85 & 7.71	178	4.34	.416
1205	5.43 & 5.43	28.0 & 27.6	8.44 & 8.49	183	4.38	.426
1206	5.43 & 5.45	27.6 & 27.8	8.63 & 8.48	183	4.35	.432
1209	6.00 & 6.07	27.9 & 27.6	9.21 & 9.01	185	4.36	.440
1210	6.04 & 6.07	28.2 & 28.0	9.20 & 8.98	181	4.42	.440
1801	6.50 & 6.61	29.8 & 30.2	9.06 & 9.06	180	4.36	.460
1802	6.60 & 6.61	30.4 & 30.5	9.15 & 9.15	186	4.36	.462

III CONSTANT: HYDROGEN FLOW, 2.09 ± .05 LB/MIN; INLET TEMPERATURE, 428 ± 1½ °R; GLYCOL-WATER INLET TEMPERATURE, 39 ± 1 °F.

RUN NO.	GLYCOL-WATER FLOW LBS/MIN.	MEAN GLYCOL-WATER TEMP °F	GLYCOL-WATER PRESSURE DROP PSI	Q_{TOTAL} BTU/MIN.	UA BTU/MIN.°R	ϵ
1701	4.22 & 4.20	23.6 & 23.5	7.33 & 7.31	179	4.51	.341
1702	4.22 & 4.20	23.4 & 24.3	7.34 & 7.15	184	4.49	.346
1703	4.80 & 4.78	25.3 & 25.9	7.65 & 7.60	185	4.60	.361
1704	4.79 & 4.78	24.6 & 24.5	7.69 & 7.63	166	4.55	.357
1705	5.43 & 5.42	24.8 & 26.2	8.30 & 8.35	202	4.91	.366
1706	5.43 & 5.42	27.2 & 27.2	8.07 & 8.07	197	4.56	.376
1707	6.06 & 6.06	27.6 & 27.7	8.07 & 8.07	206	4.63	.383
1708	6.05 & 6.05	27.6 & 27.9	8.73 & 8.91	199	4.67	.388
1709	6.61 & 6.60	28.6 & 29.0	9.23 & 9.25	199	4.56	.390
1710	6.61 & 6.60	28.8 & 29.0	9.30 & 9.31	206	4.66	.398

IV CONSTANT: HYDROGEN FLOW, 1.06 ± .01 LB/MIN.; INLET TEMPERATURE 360 ± 2°R; GLYCOL-WATER INLET TEMPERATURE, 70 ± 2 °F.

RUN NO.	GLYCOL-WATER FLOW LBS/MIN.	MEAN GLYCOL-WATER TEMP. °F	GLYCOL-WATER PRESSURE DROP PSI	Q_{TOTAL} BTU/MIN.	UA BTU/MIN.°F	ϵ
1903	4.18 & 4.20	36.2 & 36.4	5.08 & 5.05	296	3.54	.506
1904	4.18 & 4.20	36.3 & 37.6	5.08 & 5.06	298	3.58	.506
1509	4.80 & 4.78	46.6 & 46.2	5.07 & 5.06	323	3.87	.535
1510	4.80 & 4.76	46.4 & 46.5	5.07 & 5.06	321	3.86	.536
1505	5.43 & 5.45	48.1 & 48.9	5.40 & 5.28	330	3.86	.509
1506	5.43 & 5.43	49.1 & 49.1	5.38 & 5.42	332	3.86	.549
1501	6.02 & 6.04	49.7 & 49.9	5.81 & 5.82	333	3.90	.562
1502	6.02 & 6.04	50.1 & 50.1	5.83 & 5.82	329	3.92	.560
1905	6.60 & 6.62	52.6 & 51.3	6.16 & 6.05	328	3.87	.571
1906	6.60 & 6.52	52.1 & 52.7	6.17 & 6.09	336	3.92	.572

V CONSTANT: HYDROGEN FLOW, 1.64 ± .01 LB/MIN.; INLET TEMPERATURE, 360 ± 3°R; GLYCOL-WATER INLET TEMPERATURE, 70 ± 2 °F.

RUN NO.	GLYCOL-WATER FLOW LBS/MIN.	MEAN GLYCOL-WATER TEMP. °F	GLYCOL-WATER PRESSURE DROP PSI	Q_{TOTAL} BTU/MIN.	UA BTU/MIN.°F	ϵ
1805	4.21 & 4.20	38.8 & 39.8	6.04 & 6.01	367	3.98	.395
1806	4.23 & 4.20	38.0 & 38.5	6.13 & 6.05	366	4.07	.394
1309	4.80 & 4.80	41.2 & 41.4	6.45 & 6.27	390	4.30	.415
1310	4.80 & 4.80	41.4 & 41.4	6.40 & 6.20	387	4.25	.416
1305	5.44 & 5.43	43.2 & 43.3	6.58 & 6.43	410	4.40	.434
1306	5.44 & 5.43	43.4 & 43.4	6.71 & 6.44	402	4.37	.434
1301	6.04 & 6.00	45.6 & 46.2	6.76 & 6.59	410	4.38	.450
1302	6.04 & 6.00	45.6 & 45.6	6.83 & 6.71	414	4.29	.446
1807	6.57 & 6.55	47.1 & 47.4	6.90 & 6.82	420	4.40	.454
1808	6.57 & 6.55	46.9 & 47.0	6.90 & 6.82	419	4.44	.458

VI CONSTANT: HYDROGEN FLOW, 2.06 ± .04 LB/MIN.; INLET TEMPERATURE, 360 ± 2°R; GLYCOL-WATER INLET TEMPERATURE, 70 ± 2 °F.

RUN NO.	GLYCOL-WATER FLOW LBS/MIN.	MEAN GLYCOL-WATER TEMP. °F	GLYCOL-WATER PRESSURE DROP PSI	Q_{TOTAL} BTU/MIN.	UA BTU/MIN.°F	ϵ
1901	4.20 & 4.22	36.2 & 36.4	7.09 & 7.05	394	4.16	.341
1902	4.20 & 4.22	36.8 & 37.6	7.00 & 6.98	397	4.23	.341
1401	4.80 & 4.80	39.3 & 39.4	7.35 & 7.07	432	4.35	.355
1402	4.80 & 4.80	39.6 & 39.7	7.14 & 7.09	416	4.36	.352
1405	5.42 & 5.32	40.8 & 41.0	7.12 & 7.08	438	4.49	.369
1406	5.43 & 5.42	40.2 & 40.8	7.70 & 7.87	436	4.56	.372
1409	6.00 & 6.02	42.1 & 42.8	7.60 & 7.52	455	4.66	.388
1410	6.02 & 6.02	42.5 & 42.6	7.60 & 7.52	454	4.66	.388
1809	6.60 & 6.55	44.5 & 44.4	7.98 & 7.92	463	4.64	.397
1810	6.58 & 6.56	45.2 & 46.1	7.78 & 7.57	462	4.63	.397

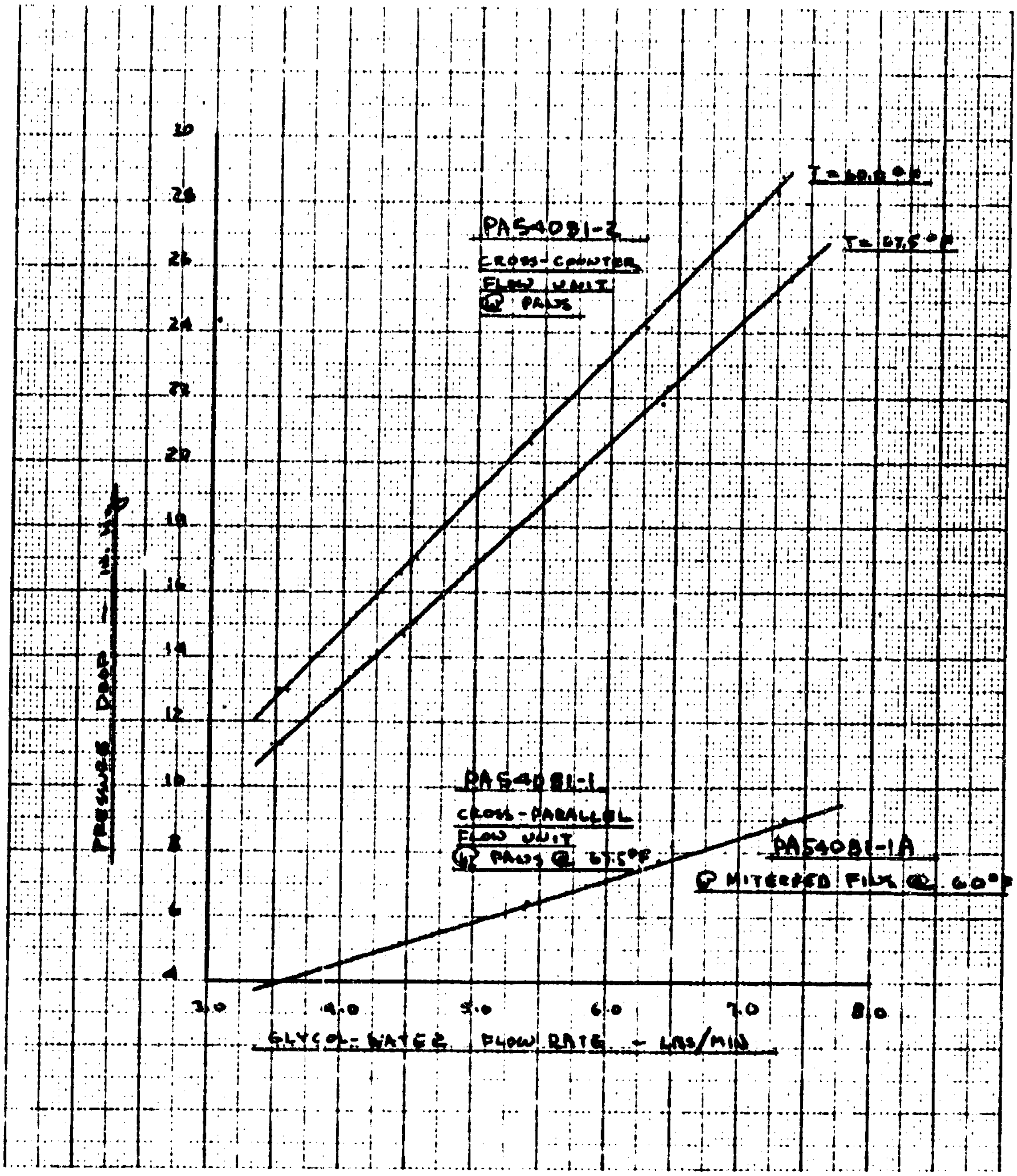


Figure 87. Isothermal Glycol Pressure Drop, Primary Heat Exchanger

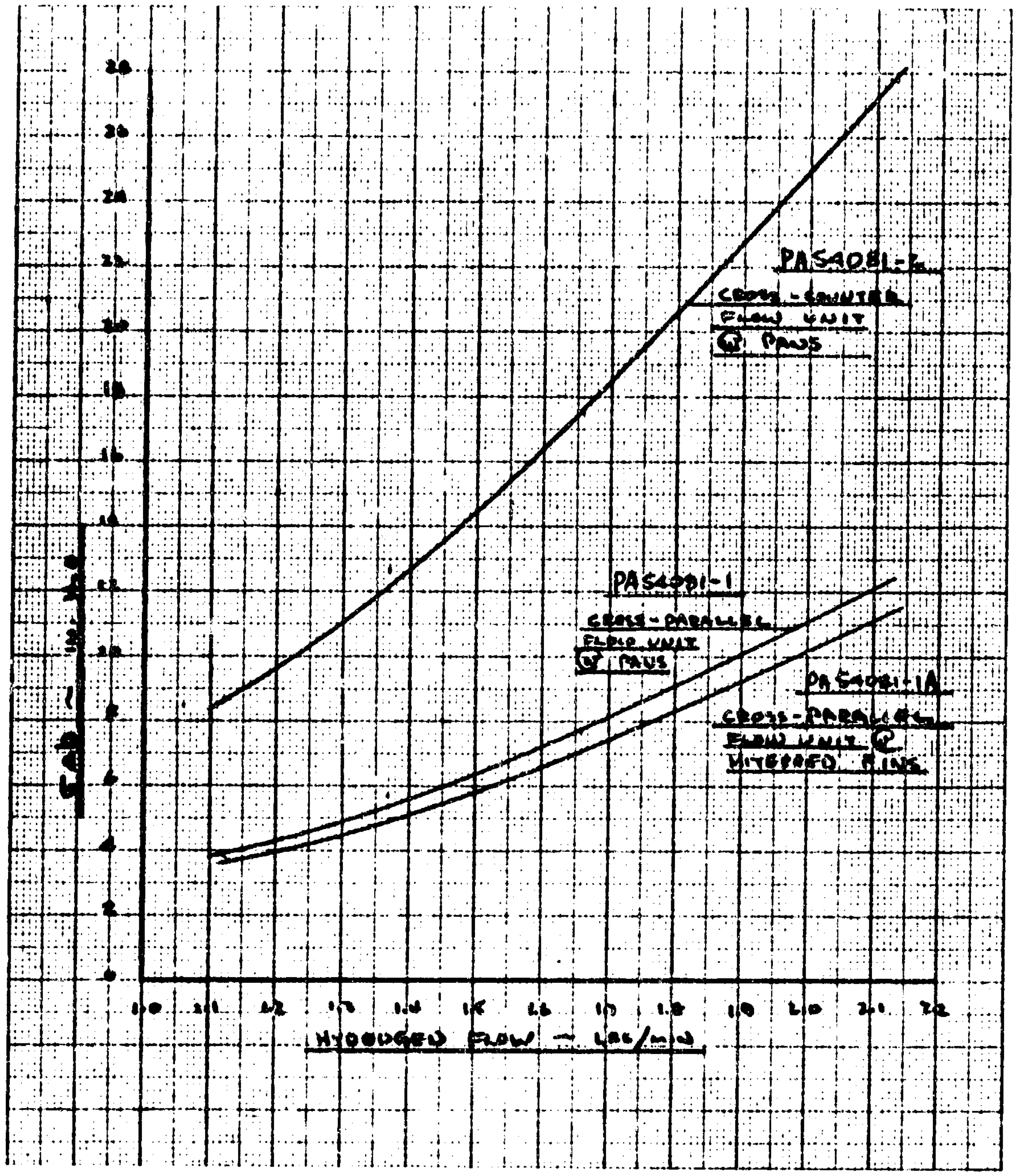


Figure 88. Isothermal Hydrogen Pressure, Drop, Primary Heat Exchanger

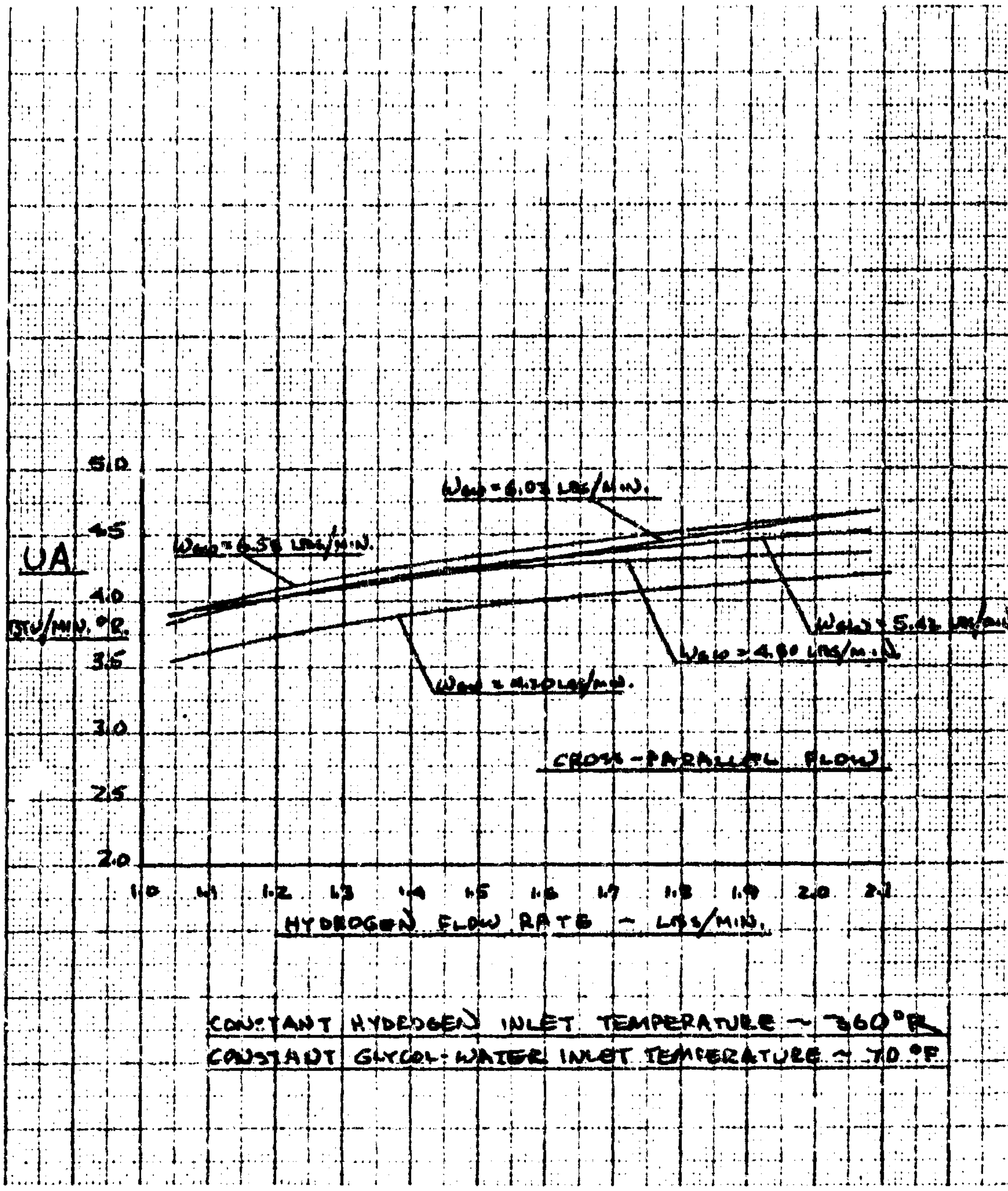


Figure 89. Overall Thermal Conductance, Cross-Parallel Flow Section

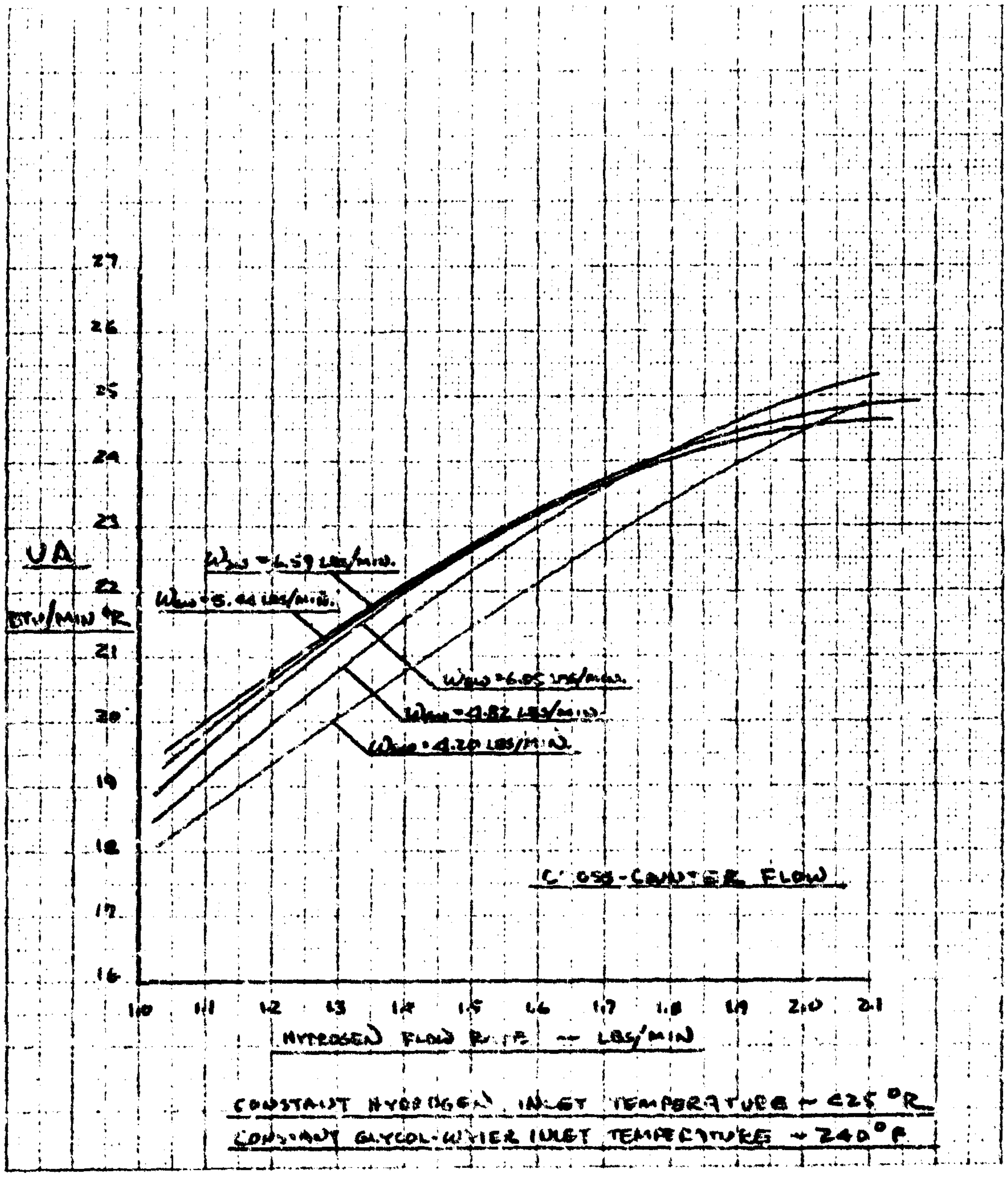


Figure 90. Overall Thermal Conductance, Cross-Counterflow Section

3. Compressor Motor Performance

The test specimen was identical to the production motor with the exception that grease-packed bearings were used. The motor was operated at room temperature and pressure. Various loads were imposed from no-load to the locked rotor condition. Torque, speed, power input, phase voltage and phase current were recorded. The motor performance curve is presented in Figure 91.

4. Compressor Motor Starting Transients

The test loop included provision for regulating the inlet temperature and pressure, and the pressure rise of the compressor. The test fluid was nitrogen, regulated to the density of hydrogen under the normal operating conditions.

With rated three-phase power source connected through an oscillograph to the test unit motor, the oscillograph was calibrated to register line voltages and currents (rms) as graphic traces for each phase. Displacements of rated voltages and currents were referenced to a predetermined linear scale.

The compressor was chilled to -100°F ±10°F by circulating low-temperature nitrogen through the test loop prior to running the test. Initial test runs on the compressor were made at the low temperature to set the flow rate and pressure rise. The compressor was then turned off. With the oscillograph operating, the compressor was turned on. The voltage, current, and motor speed were recorded by the oscillograph from zero time through the period required to obtain steady-speed motor operation.

The results of the starting transient test are shown in Figure 92. The time required for the motor to reach operating speed from a dead stop is 2.6 sec. While current in Phase 2 was consistently higher than the other phases throughout the starting period and substantially higher during the initial period, each current trace was similar in form. All voltages remained constant throughout the test; however Phase 1 and 2 were 120v and Phase 3 voltage was 115 v.

During start-up, each starting current remained constant for approximately 20 percent of the starting period, although Phase 2 current was 1.8 amp and Phase 1 and 3 currents were approximately 1.6 amp each. Current in each phase dropped abruptly as the motor reached two-thirds operating speed (between 1.6 sec and 2.2 sec). At recorded speed of 22,900 rpm, the operating current of Phase 2 was 0.45 amp and currents of Phases 1 and 3 were approximately 0.35 amp each.

The inconsistency between phase currents is believed to be a result of the unbalanced supply voltages. The resistance of the motor windings themselves were found to be equal at room temperature and at -100°F. The unbalance was to have been investigated further with carefully regulated voltages during the power system compatibility test, but this latter test was not completed before the contract cancellation.

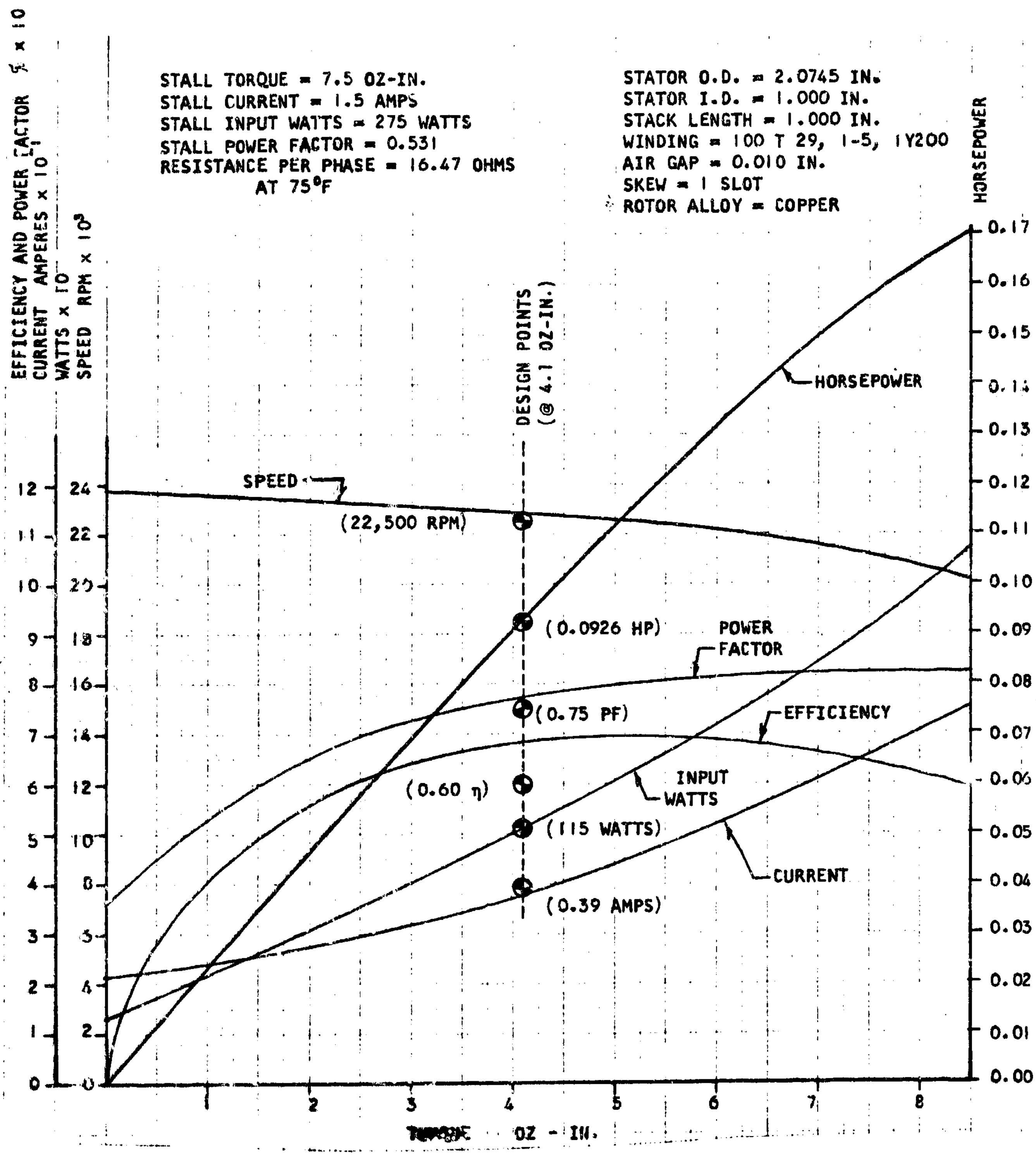


Figure 91. Compressor Motor Performance

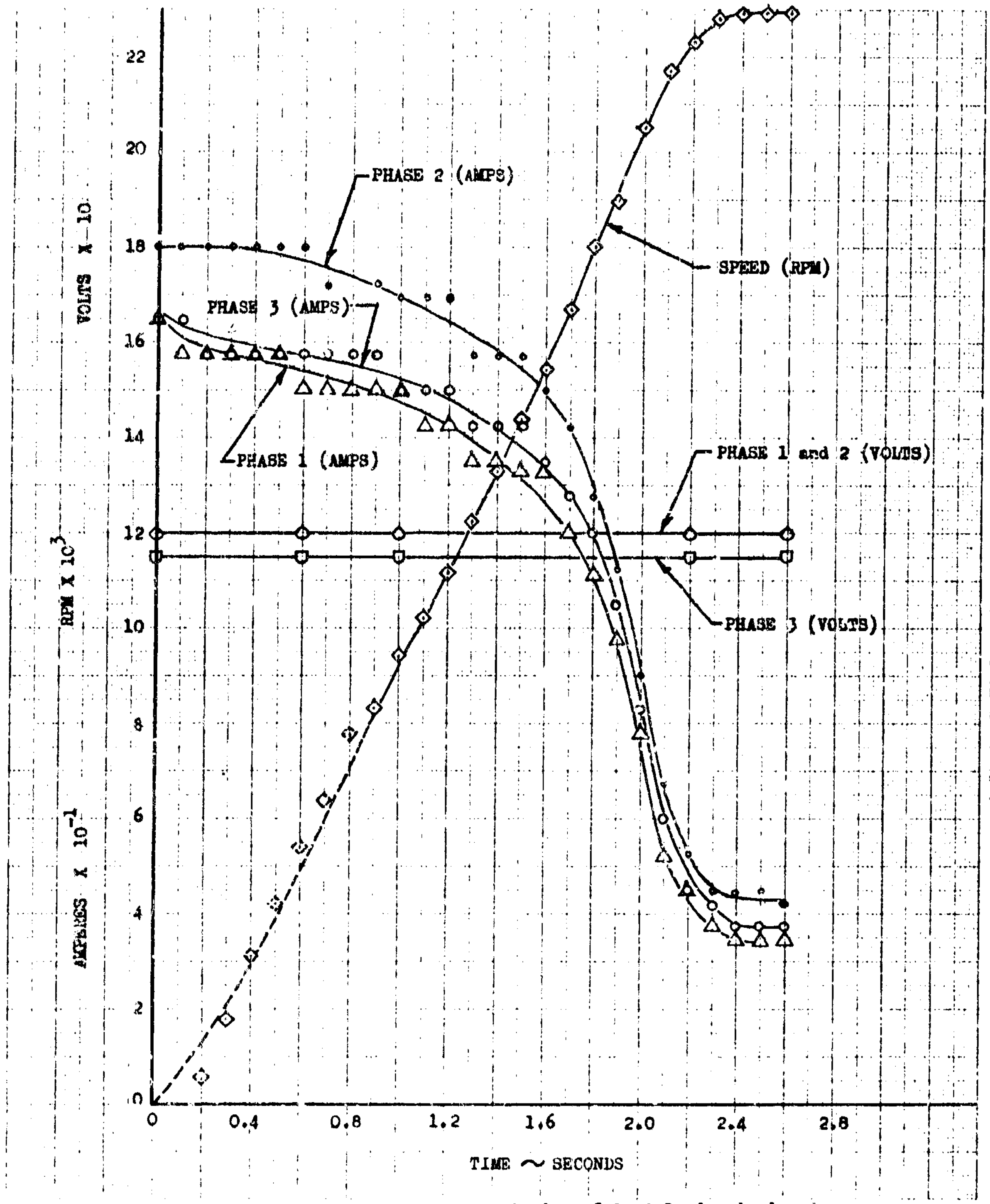


Figure 92. Compressor Motor Starting Transients

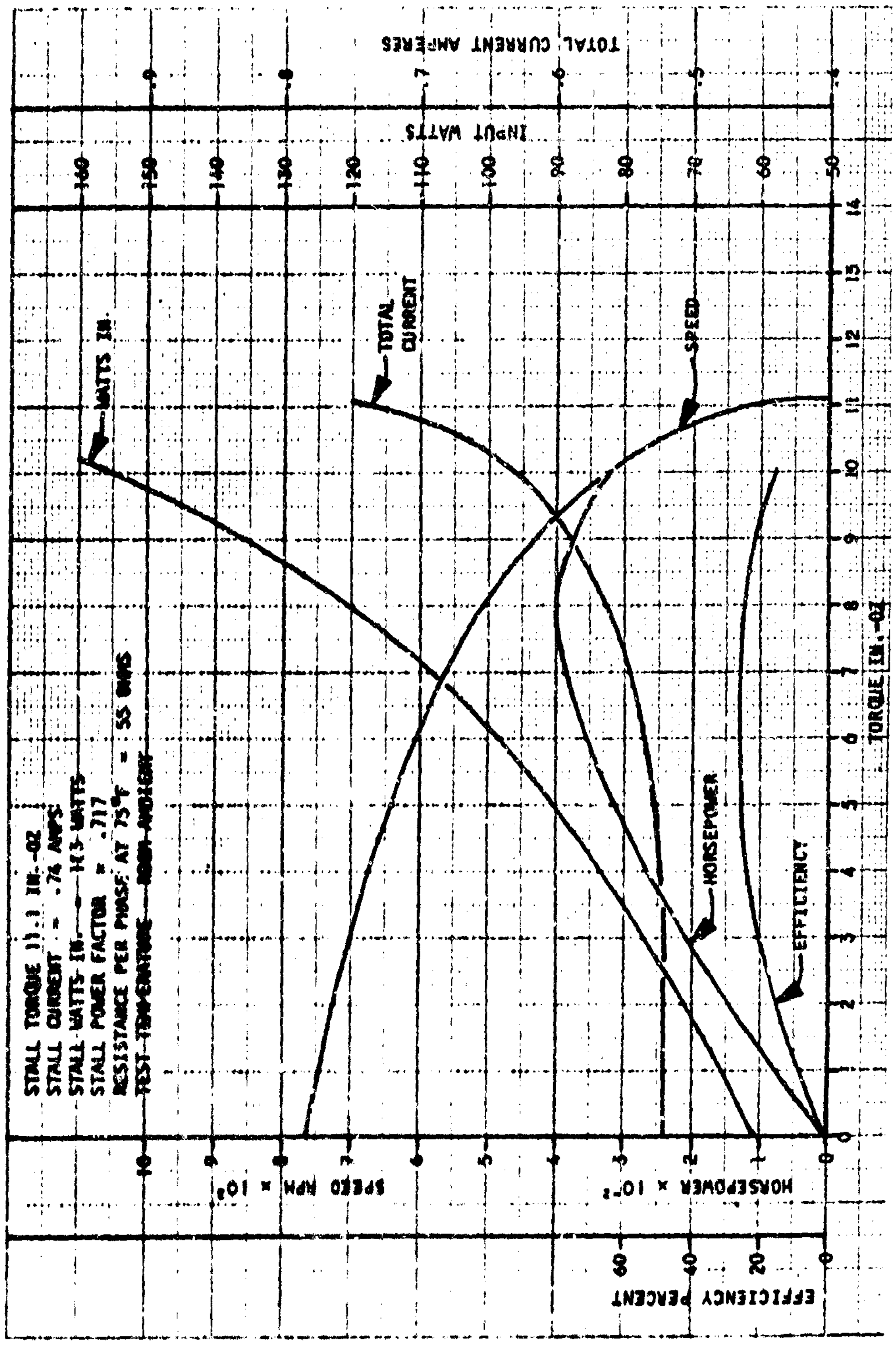


Figure 53 Pressurization Fan Motor Performance

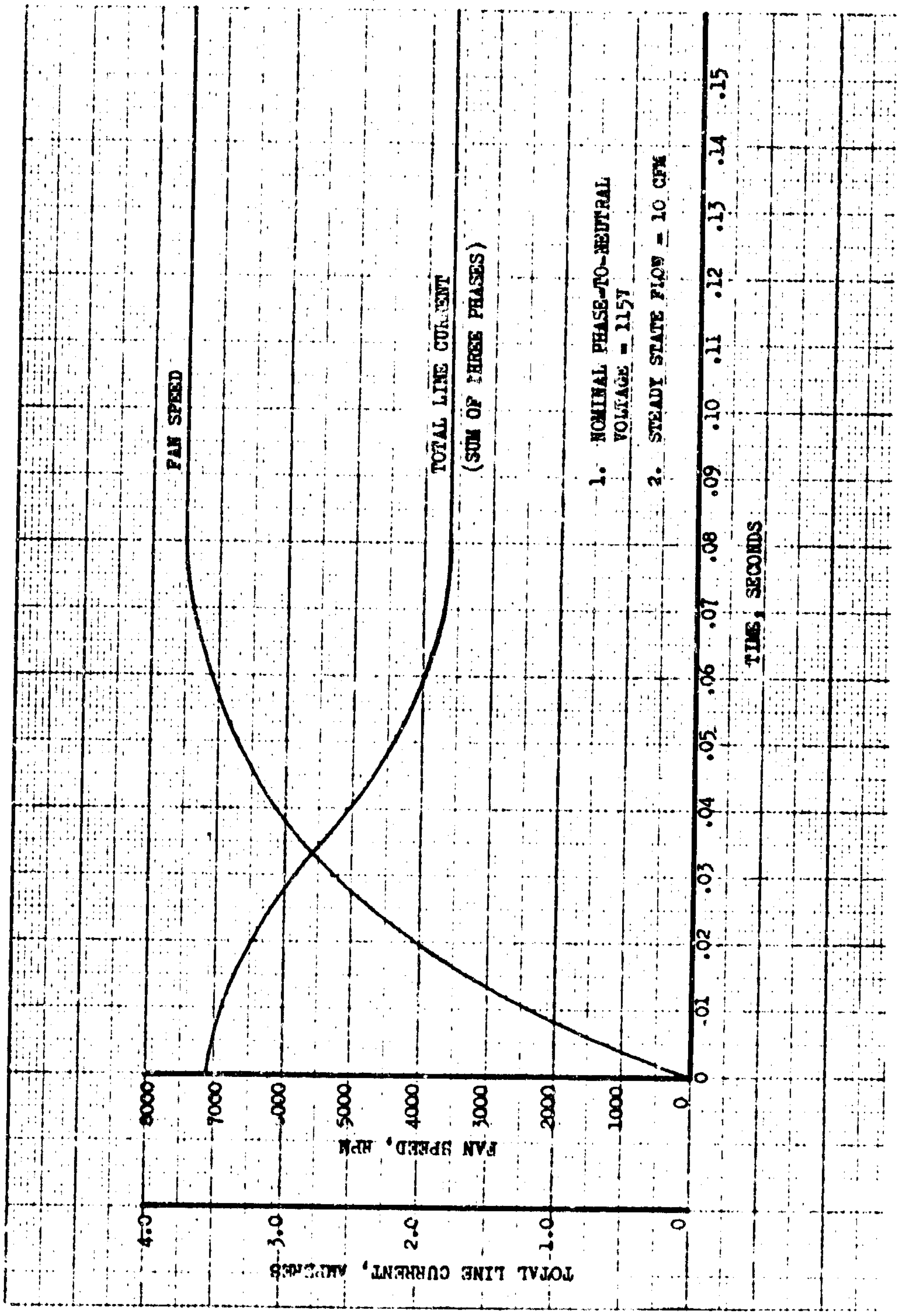


Figure 94. Pressurization Fan Motor Starting Transient

5. Pressurization Fan Motor Performance

The test specimen was identical to the production motor with the exception that grease-packed bearings were used. The motor was operated at room temperature and pressure. Various loads were imposed from no-load to the locked rotor condition. Torque, speed, power input, phase-to-neutral voltage, and phase current were recorded.

The motor performance curve is presented in Figure 93.

6. Pressurization Fan Motor Starting Transients

The starting transients were measured with the fan installed in a closed loop simulating the service installation as nearly as practical. The gas in the loop was nitrogen instead of hydrogen, and the temperature was -220°F instead of -420°F, but the pressure waa adjusted to simulate the hydrogen density in the pressurization loop, 4.6 lb per cu ft.

The fan was turned on and the back-pressure was adjusted to permit a flow of 10 cfm. The fan was turned off and allowed to stop. Then, with the oscillograph running, the fan was turned on and the current and speed transients were recorded.

The starting transients are shown on Figure 94

The test unit was installed in the aerodynamic test setup as shown in Figure 95.

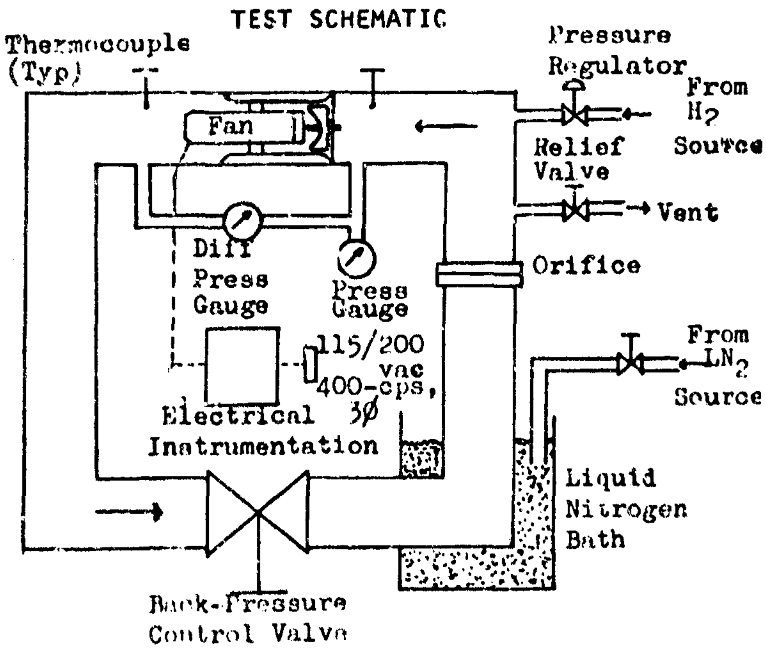


Figure 95 Fan Aerodynamic Test Setup

The circulating gaseous nitrogen was cooled to -220°F in a bath of liquid nitrogen. Nitrogen at densities of 4.6, 2.5 and 0.5 lb per cu ft were circulated at the referenced temperature. The throttle valve was varied from full closed to full open for each of these density levels of nitrogen circulated.

The results of the aerodynamic performance tests are given in Figure 96.

7. Pressurization Heat Exchanger Performance

The hydrogen test loops were initially evacuated and charged with hydrogen gas to 385 psig. Cold-hydrogen test unit inlet temperature was adjusted and maintained between -194°F and -222°F. Warm hydrogen test inlet temperature was adjusted and maintained between 139°F and 161°F. Steady-state heat rejection and warm hydrogen-side pressure drop were recorded at the following flows:

Cold H_2 Flow, lb per min	Warm H_2 Flow, lb per min
2.48	0.3, 0.4 and 0.5
4.30	0.3, 0.4 and 0.5

The test results are presented in the form of curves. Figure 97 presents the thermal conductance test results. Superimposed on this curve is the calculated design UA required. This UA is based on the most severe heat rejection requirements of this heat exchanger. This condition exists at 5.0 lb per min cold H_2 flow and 0.5 lb per min warm H_2 flow. A cold hydrogen flow of 5.0 lb per min could not be attained because of operational limitations in the test setup hardware. To provide an approximate indication of the performance of this test unit at the design flow of 5.0 lb per min, the test results were extrapolated to 5.0 lb per min. The estimated thermal conductance was then plotted as a dashed line in Figure 97 and indicates that the test unit meets the design requirements with a 4.8 percent margin.

Figure 98 presents the corrected static pressure drop on the warm hydrogen side. This pressure drop includes entrance and exit plumbing losses and the heat exchanger core losses. Superimposed on this plot is the predicted core pressure loss at design flow, and also the predicted core loss plus the entrance and exit plumbing losses. The test results indicate the pressure drop is approximately 24 percent higher than predicted.

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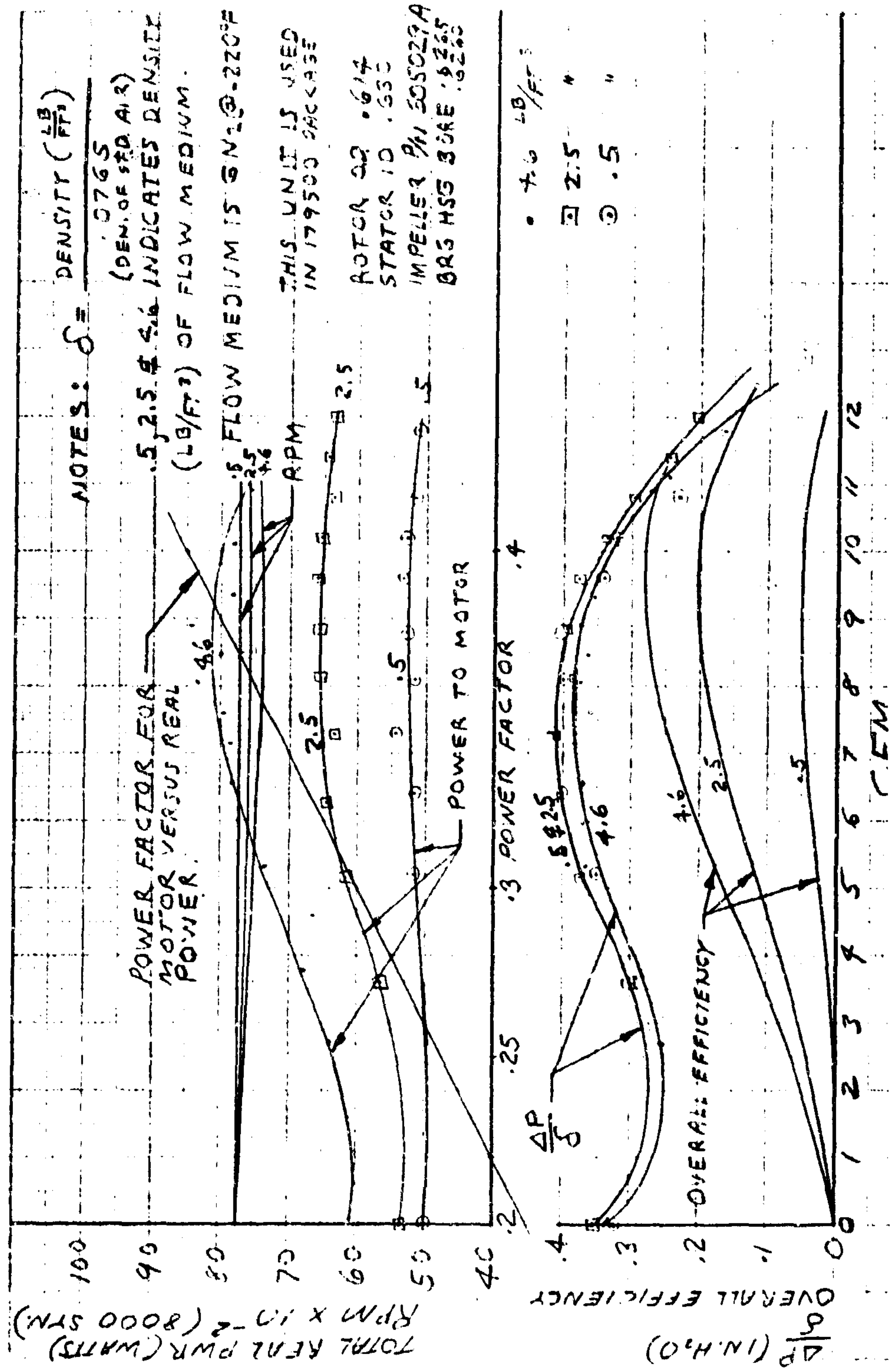

Figure 96 Fan Aerodynamic Performance

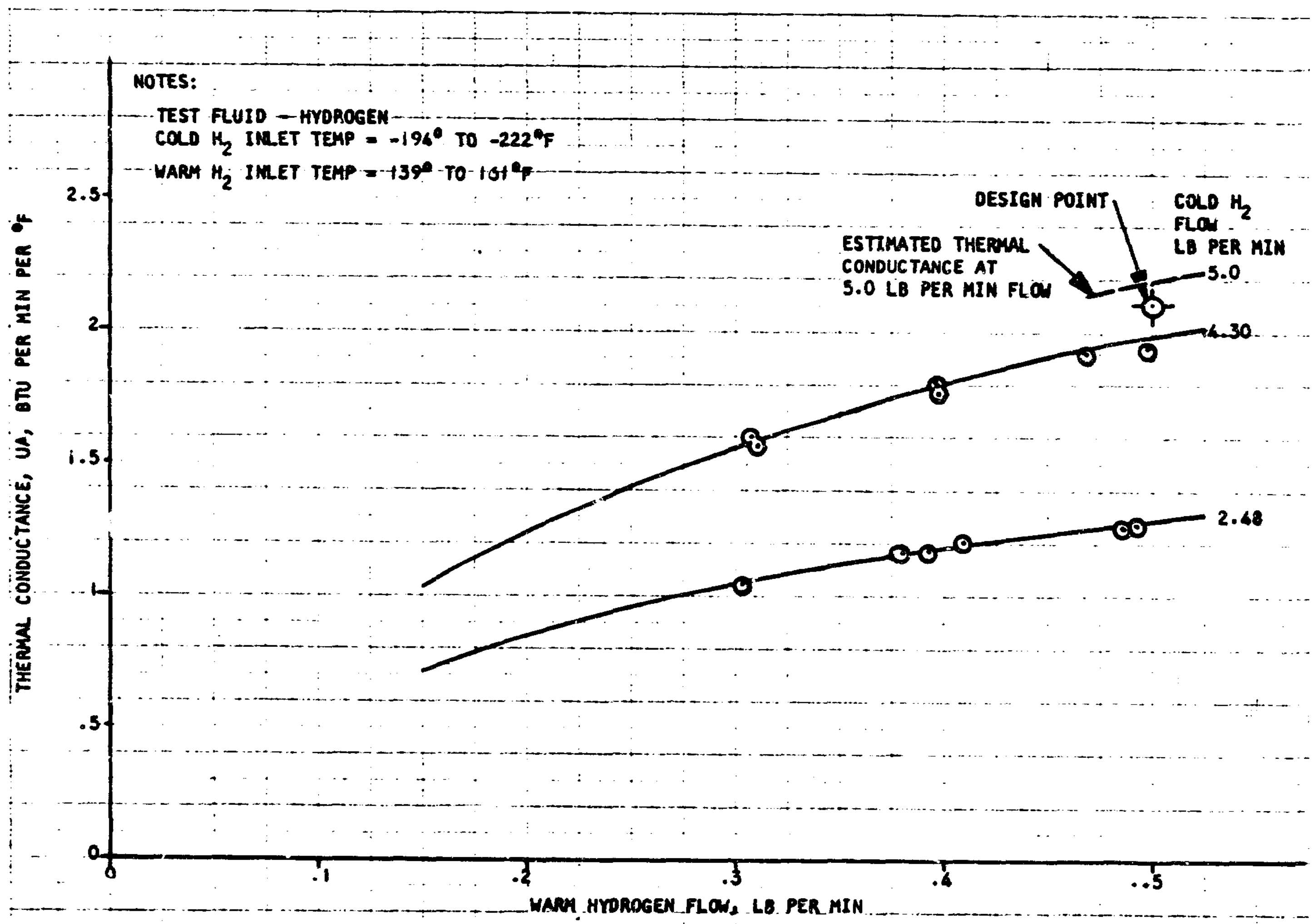

Figure 97. Overall Thermal Conductance, Pressurization Heat Exchanger

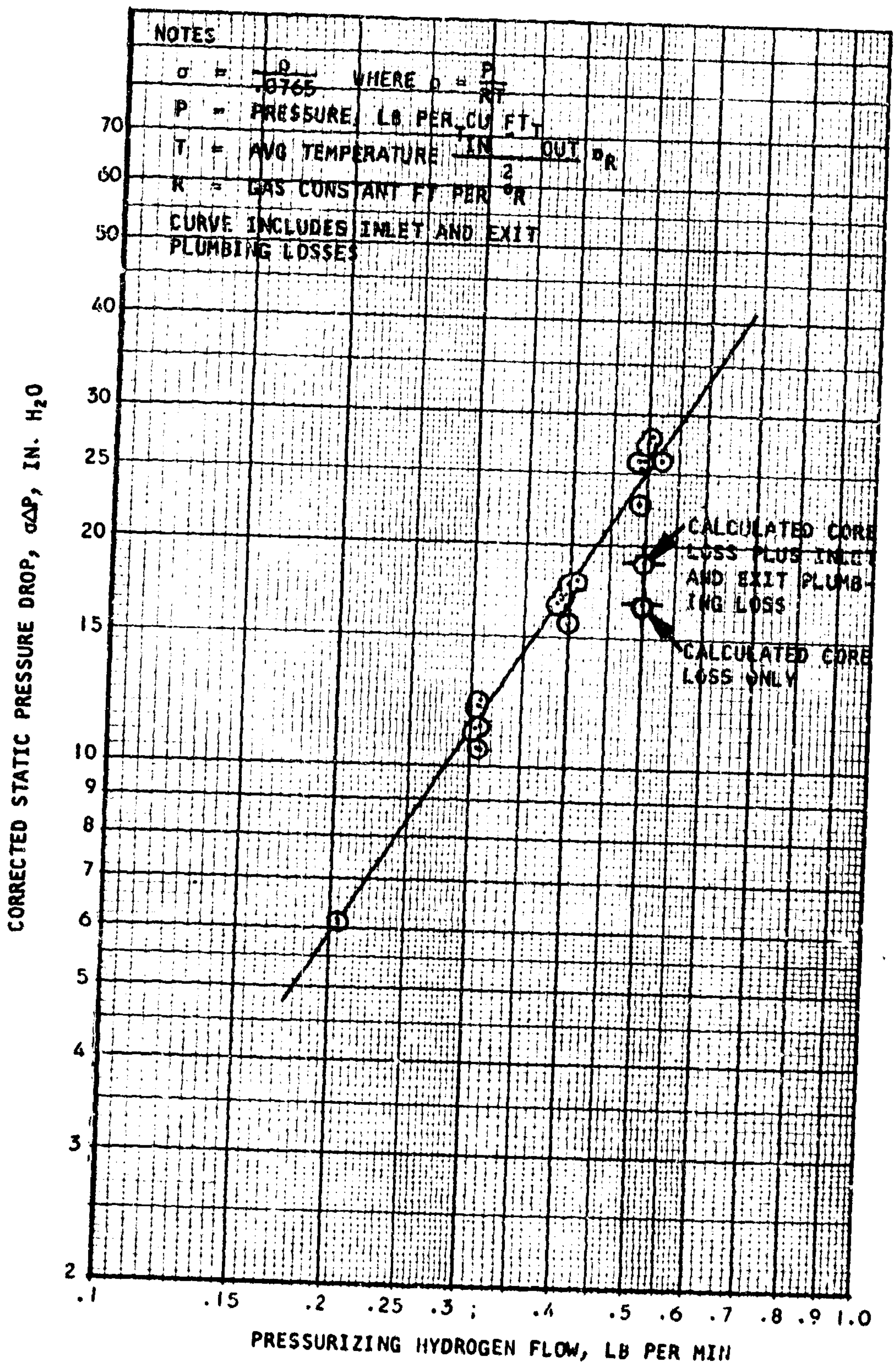

Figure 98 Nonisothermal Pressure Drop, Pressurization (Warm) Side of Pressurization Heat Exchanger

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13. ABSTRACT

This report includes work performed under Contract AF33(615)-1898 as a continuation of Contract AF33 (657)-7132 and covered the development of a cryogenic thermal management system for the Air Force X-20A (Dyna-Soar). The work completed under this contract was the fabrication, assembly and acceptance testing of the system components that had been developed prior to cancellation of the former contract.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
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